A Textbook of

Biology

Grade XI

Test Edition

KHYBER PAKHTUNKHWA TEXTBOOK BOARD, PESHAWAR

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Chapter 1

Cell Structure and Function

At the end of this chapter the students will be able to:

- List the principles and identify the apparatus used in the techniques of fractionation, differential staining, centrifugation, microdissection, tissue culture, chromatography, electrophoresis and spectrophotometry.
- Describe the terms of resolution and magnification with reference to microscopy.
- Explain the use of graticule and micrometer and define the units used in micrometry.
- Describe the locations, chemical compositions and significance of the primary cell wall, secondary cell wall and middle lamella.
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Introduction

One of the most important concepts in biology is that the basic unit of structure and function in living organisms is the cell. It is the smallest unit that can carry out all activities of life. Cells are the building blocks of complex multicellular organism.

The modern theory of cellular organization states that,

1. All living organisms are composed of one or many cells.
2. All new cells arise from by the division of pre existing cells.
3. Cells contain the hereditary material of an organism which is passed from parent to daughter cells.
4. All metabolic processes take place within cells.

> **Tidbit**
>
> The oldest accurately dated life form is a microorganism, *Eubacterium isolatum* which dated back 3500 million years.

1.1 Techniques used in Cell Biology

Microscopy makes a very valuable contribution to our understanding of cells. However, techniques are also needed if the functions of organelles are to be studied. Various techniques have been used for isolating and examining various cell components. Of these, differential staining, centrifugation, tissue culture, chromatography, electrophoresis etc are the most common techniques. The examination of a cell and its component depends upon the magnification powers of two convex lenses to produce a magnified image of a very small object.

Table 1.1 Magnification of the Microscope

Objective lens	Eye piece lens	Magnification of object
x 10	x 6	x 60
x 40	x 6	x 240
x 10	x 10	x 100
x 40	x 10	x 400

1.1.1 Resolution versus magnification of microscope

The biologists who study cells, use different devices and precise techniques in their efforts to develop exact descriptions of cells and their parts. Their most important tool is the compound light microscope. It is very useful but it is limited by the nature of the energy it uses i.e light. The limitation of any microscope defined as resolving power; the ability to distinguish close objects as being separate from one another.

The resolving power of light microscopes is 250nm. This resolution power is about 500X is that of naked eye. The human naked eye can differentiate between two points at least 1.0mm apart. Different light microscopes have been developed with different resolution and magnification powers. Magnification is a mean of increasing the apparent size of the object being viewed to a reasonable size. With a light microscope a specimen could quite easily be magnified by as much as 1000 to 2000 times. Fortunately, we are not dependent only on the resolving powers of the light microscope. We now have the Transmission Electron Microscope (TEM). The TEM can magnify an object upto 1,000,000 (1 million) times. One recent innovation, the Scanning Electron Microscope (SEM) has produced three dimensional images of whole objects.

1.1.2 Staining

Most biological structures are transparent so that some techniques of obtaining contrast between different structures must be employed. The most common method is staining. It is a process of treating a specimen for examination under the microscope with a reagent or dye. This makes certain structures visible without affecting others. Some of the stains used in light microscopy are shown in table 1.2. Certain stains when used in low concentration are non-toxic to living tissues and can therefore be used on living materials. Two stains may be used in which the first stain is called principal stain and the second as counter stain. Counter stain is stain of a contrasting color used to color the components in a microscopic specimen that are not made visible by the principal stain. These stains are called **vital stains.** For example, methylene blue and neutral red. Two stains may be used in which the second is called **counter stain**.

Table 1.2 Profile of Permanent Stains

Stains	Final Colour	Suitable for
i. Aniline blue	Blue	Fungal hyphae & Spores
ii. Borax carmine	Pink	Nuclei, Obelia colony
iii. Eosin	Pink / Red	Cytoplasm / Cellulose
iv. Feulgen's stain	Red / Purple	DNA (particularly during cell division) i.e. chromosomes
v. Leishman's stain	Red / Pink / Blue	Blood cells
vi. Methylene blue	Blue	Nuclei
vii. Safranin	Red/ Purple	Nuclei, lignin & plant tissues

Table: 1.3 Profile of Temporary Stains

Stains	Final Colour	Suitable for
i. Aniline sulphate	Yellow	Lignin
ii. Iodine solution	Blue-black	Starch
iii. Schultz's solution (Chlor-zinc-iodine)	Yellow / Blue / Blue or Violet	Lignin, Cutin, Protein. / Starch / Cellulose

As revealed by the above table different cell organelles stain differently by different stains, hence increase the resolution power of a microscope.

1.1.3 Centrifugation (cell fractionation)

Dividing the cell into its parts or fractions is called cell fractionation. It is done in a centrifuge and the process is called centrifugation. Cell fractionation can isolate various components of cells including organelles according to their particular size and density. This process is accomplished in the following manner.

- The first step is grinding up the tissue in a liquid medium of proper osmotic concentration to form a homogenate, which is then put in a centrifuge and spun.
- Initially it is spun at a relatively slow rate to separate out the larger, heavier part of the homogenate, such as any remaining whole cells and the nuclei.
- When these fractions have been removed, the remaining material is again spun at a speed and cellular components of intermediate size, such as mitochondria, plastids etc precipitate out and are removed.
- The supernatant liquid can then be spun at still higher speeds and smaller, lighter cellular fractions are precipitated.

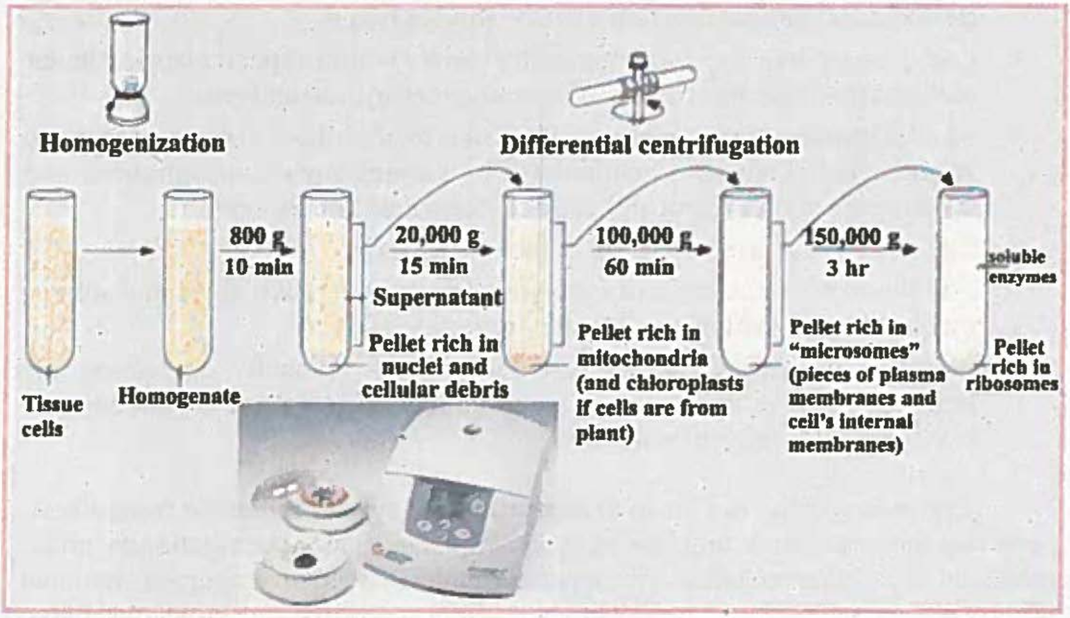


Fig 1.1 Cell fractionation technique.

1.1.4 Tissue Culture

Tissue culture is the growth of tissues and cells separate from the organism. This is typically facilitated by the use of liquid semi-solid growth medium such as broth,or agar. Tissue culture produces clones in which all the product cells have the same genotypes unless affected by mutation during culture. In the following

sections a list of apparatus and main steps of tissue culture are given:

A. Tissue Culture Apparatus

- Cell culture hood (i.e., laminar-flow hood or biosafety cabinet)
- Incubator (humid CO_2 incubator recommended)
- Water bath
- Centrifuge
- Refrigerator and freezer (–20°C)
- Cell counter
- Inverted microscope
- Liquid nitrogen (N_2) freezer or cryostorage container
- Sterilizer (i.e., autoclave)

B. Main steps in tissue culture

1. Selection of the plant tissue (explant) from a healthy vigorous mother plant. This is often the apical bud but can be other tissue.
2. This tissue must be sterilized to remove microbial contaminants.
3. Establishment of the explant in a culture medium. Medium sustains the plant cells and encourages division it can be solid or liquid.
4. Each plant species (and sometimes the variety within a species has particular medium requirements that must be established by trail and error.
5. Multiplication of the explant gives rise to a callus (a mass of loosely arranged cells) which is manipulated by varying sugar concentrations and the auxin (low) cytokinin high ratios to form multiple shoots.
6. The callus may be subdivided a number of times.
7. The shoots are transferred to a growth medium with relatively higher auxins, cytokinin ratios which results in the formation of roots.
8. Plantlets are deflasked and hardened off by gradually decreasing the humidity. This is necessary as many young tissue culture plants have no waxy cuticle to prevent water loss.

1.1.5 Chromatography

Chromatography is a mean of separating one type of molecule from others. It involves moving the mixture, normally as a liquid or a gas, over a stationary phase embedded in cellulose or silica. The separation may depend on a range of chemical and physical properties of the molecules such as solubility and molecular mass. Essentially there are two basic ways of carrying out the separation.

a. Paper Chromatography

It is used for the separation of photosynthetic pigments, sugar or amino acids. The mixture is spotted near one end of a paper strip and then dipped into a

specific solvent which moves through the paper by capillary action carrying the molecules with it. Similarly, a thin layer of silica may be used instead of paper.

b. Column Chromatography

It is more commonly used method which involves the mobile phase flowing over a supporting matrix held in a glass or metal tube.

1.1.6 Electrophoresis

It is a technique used to separate molecules of different electrical charge. Under the influence of different electrical field, negatively and positively charged ions (Molecules) will move towards anode (+) and cathode (-) respectively. Two factors affect the speed with which charged molecules move towards an electrode.

i) The amount of charge (greater charge, faster movement & vice versa)

ii) The size of molecules (smaller molecules, faster movement & vice versa)

1.1.7 Spectrophotometery

This technique is used to measure the change in percentage transmission of light (Optical density) of the suspension material. The cell mass is directly proportional to the optical density. The determination of amino acids by spectrophotometeric analysis is based upon specific light absorption. Such analysis of the amino acid generally depends upon absorption exhibited by their colored derivatives.

1.1.8 Microdissection

It refers to a variety of techniques in which microscope is used to aid the process of dissection cells or it organelles. Different kinds of techniques involve microdissection:

- Chromosome microdissection — use of fine glass needle under a microscope to remove a portion from a complete chromosome
- Laser micro dissection — use of a laser through a microscope to dissect selected cells
- Laser capture microdissection — use of a laser through a microscope to cause selected cells to adhere to a film.

1.2 Micrometry (measurement of size with the microscope)

It is obviously important to be able to make accurate measurement of the real size of structures seen with the microscope. Measurement of microscopic objects is called micrometry. This can be done by using specially designed scales. One of the scales is placed in eye piece (eye piece graticule) or ocular micrometer and other on the stage (stage micrometer). The micrometer has equally spaced divisions. Before using the eye piece micrometer to measure a particular structure, you will have to find out the real width of each unit on the scale at each magnification. In other words

you will have to calibrate the micrometer. This can be done by replacing the specimen with the stage micrometer, and using this to measure the eye piece units at each magnification.

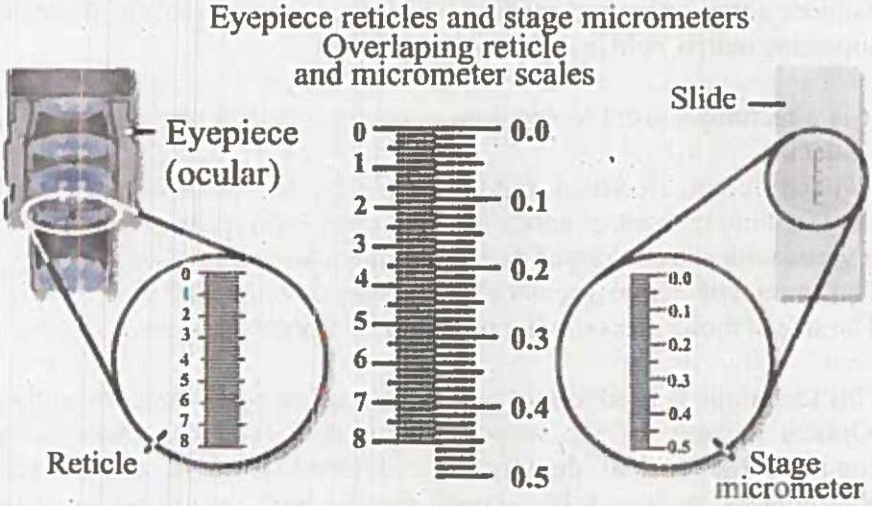


Fig 1.2 Stage & ocular micrometer

1.3 Cell Wall and Plasma Membrane

1.3.1 Cell Wall

The cell wall was discovered by Robert Hooke in 1665 earlier than the protoplast. It is the outer most boundary of the plant cells. It is secreted by the protoplasm of the cell. Its thickness varies in different cells of the plant.

Each cell whether isolated or occurring in tissues has its own cell wall. Cell walls of neighboring cells are held together by an intercellular substance called middle lamella.

Cell wall varies greatly in morphology and chemical composition but its characteristics have a close relation with the age and function of the cell on the basis of development and structure.

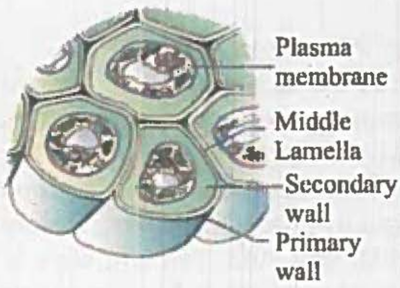


Fig 1.3 Cell wall

For your information

Cellulose, a cell wall component, can be used in Industries in the following ways:

1) Nitrocellulose (Explosives)
2) Rayan (Textile fiber)
3) Cellophane (Partially permeable membrane)
4) Plastics including celluloid's & cinematography
5) Paper making

The cell walls have three fundamental parts namely i) Middle lamella ii) Primary wall iii) Secondary wall.

Middle lamella cements together the walls of the neighboring cells. It is usually thin and about 1 μm in thickness. In woody tissues the middle lamella is commonly lignified.

Primary wall is the first wall formed in a developing cell. It is usually 1-3 μm in thickness. More or less elastic and extendable, crystalline and optically active. It is composed of cellulose, pectic compounds mostly polysaccharides and hemicellulose.

The secondary wall follows the order of primary wall in development. It is laid down inside the primary wall. Its thickness is about 5-10 μm, more or less rigid, crystalline, and strongly optically active. It is mainly composed of lignin, cellulose, non-cellulosic polysaccharides, hemicelluloses and mineral salts of Ca, Mg, K, and some silica.

A major role of the cell wall is to form a framework for the cell to prevent over expansion. Cellulose fibers, structural proteins, and other polysaccharides help to maintain the shape and form of the cell.

1.3.2 Plasma Membrane

Plasma membrane or cell membrane is the outer most boundary of the animal cells and inner to cell wall in plant cells. Cell membrane is chemically composed of lipids (20-40%) and proteins (60-80%). In addition there is small quantity of carbohydrates present.

Many biologists contributed to establish the structural organization of cell membrane. The modern technology has revealed that lipid bilayer is not sandwiched between two protein layers. In 1972, Singer and Nicholson proposed a most acceptable model for membranes called **Fluid Mosaic Model**. This model is in agreement with photograph of cell membrane by electron microscope. This model explains that "the membrane is like a sea of lipids in which protein are floating".

a. Role of Proteins

The proteins are not arranged in sheet but as globes of proteins which are floating about in the sea of lipid molecules. Some proteins extend completely through the double layer of lipids from one side to the other and are called intrinsic proteins. Some other proteins are smaller and are placed among the phospholipids molecules. These are on one side of the membrane and are called extrinsic proteins. Carbohydrates extend out from the outer surface of the membrane and are attached either to membrane lipids as glycolipids or to proteins as glycoproteins.

b. Role of Glycolipids and Glycoprotein

Lipids, proteins and carbohydrates are responsible for functional diversity of the membranes. Lipid bilayer makes the membrane differentially permeable barrier that allows the transport of non-polar materials across it and prevents ionic materials. Membrane proteins on the other hand makes it selectively permeable barrier that select materials according to cell's need. If glucose concentration inside the cell is proper, no more glucose can enter the cell. Extrinsic proteins function as receptor that receives the stimuli from the environment and thus inform the cell to respond. Integral proteins also called as "permeases" regulate diffusion, osmosis and active transport of ionic materials.

For your information

Chronological developments towards Fluid Mosaic Model of Plasma Membrane

- Gorter & Grendel 1925: -Two layers of lipid molecules only
- J F Danielle & Davson 1935:-Lipid bilayer is covered with proteins & protein pores
- Robertson 1959: - Unit membrane model
- S J Singer & G L Nicholson 1972: - Fluid mosaic model

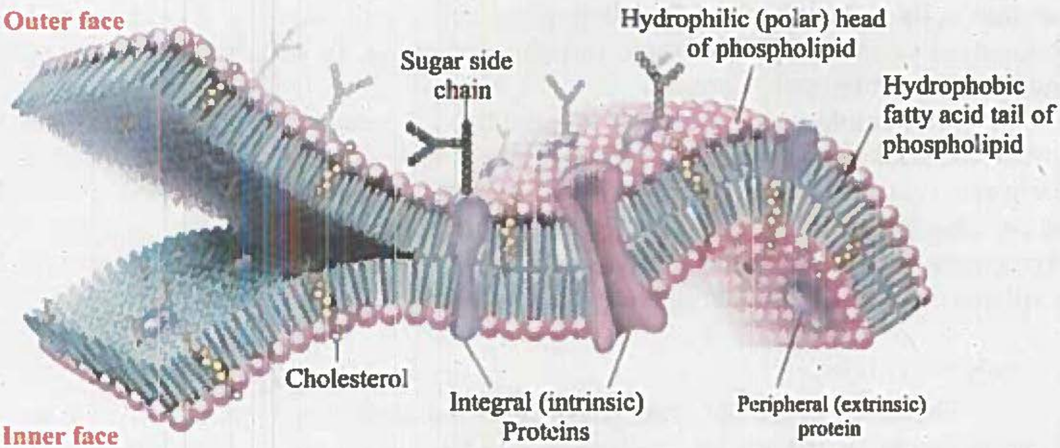


Fig: 1.4 Fluid mosaic Model

Membrane carbohydrates such as glycolipids and glycoproteins provide receptor sites that receives different types of stimuli like Hormone Receptor Sites (HRS), receives nerve impulses, recognition of antigen and food materials thus inform the cell for response. Membrane carbohydrates are also responsible for Endocytosis i.e. phagocytosis (eating of the cell) and pinocytosis (drinking of the cell). Thus glycolipids and glycoproteins act as cell surface markers.

1.3.3 Role of Plasma membrane

Plasma membrane is a dynamic structure only about 7 nm wide but it present barrier to the movement of ions and molecules, particularly polar (water soluble) molecules such as glucose and amino acids, which are repelled by the non-polar, hydrophilic lipids. This prevents the aqueous contents of the cell from escaping.

However, transport or maintenance across membranes must still occur for a number of reasons, for example

- To obtain nutrients.
- To excrete waste substances (urea, uric acid etc).
- To secrete useful substances (hormones, enzymes, etc).
- To generate the ionic gradients essential for nervous & muscular activity.
- To maintain a suitable pH and ionic concentration with in the cell for enzyme activity.

1.4 Cytoplasm

The living contents of eukaryotic cells are divided into nucleus and cytoplasm, the two together forming the protoplasm. Cytoplasm is aqueous (water containing) substance containing a variety of cell organelles and other structures such as insoluble wastes and storage products.

The soluble part of the cytoplasm forms the ground substance between the cell organelles and is called cytosol. It is formed of about 90% water and forms a solution which contains all the fundamental biochemicals of life. In cytosol, small molecules and ions may form true solutions, and some large molecules form colloidal solutions. A colloidal solution may be a **sol** (non-viscous) or a **gel** (jelly like or viscous). Often the outer region of cytoplasm is more gel like.

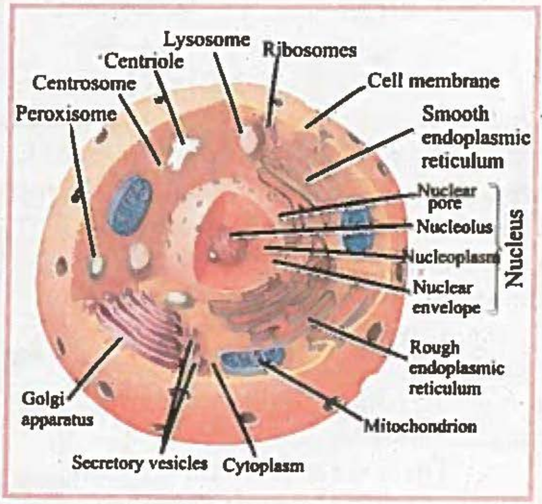


Fig 1.5 Animal cell

Apart from acting as storage of vital chemicals, the ground substance (cytosol) is the site of certain metabolic pathways, such as glycolysis. In living cells the cytoplasm contains several cell organelles such as endoplasmic reticulum, mitochondria, Golgi complex, nucleus, plastids, ribosomes, lysosomes, centrioles and various others. In the cytosol mitochondria move about in cytoplasm due to

cytoplasmic streaming movements. This is an active mass movement of cytoplasm which is called cyclosis.

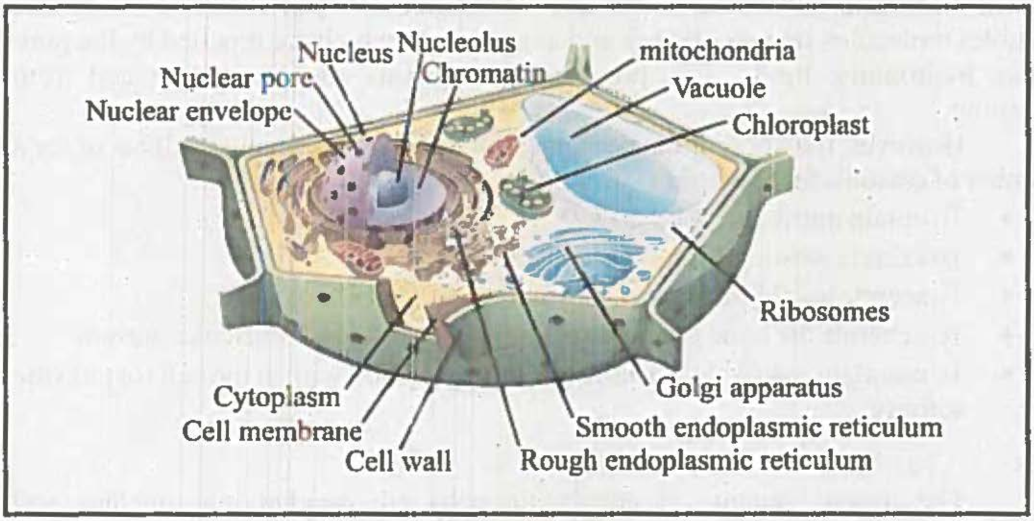


Fig: 1.6 Plant cell

1.4.1 Cytoplasmic Organelles

I. Endoplasmic Reticulum

Under the electron microscope a net work of channels is seen running through the cytoplasm of all the eukaryotic cells. These channels are often continuous with plasma membrane and also appear to be in contact with the nuclear membrane. The whole system of channels is said to be endoplasmic reticulum. These membranes vary widely in appearance from cell to cell. These channels are separated from the cytoplasmic materials by the spherical or tubular membranes one above the other, called cisternae (singular: cisterna).

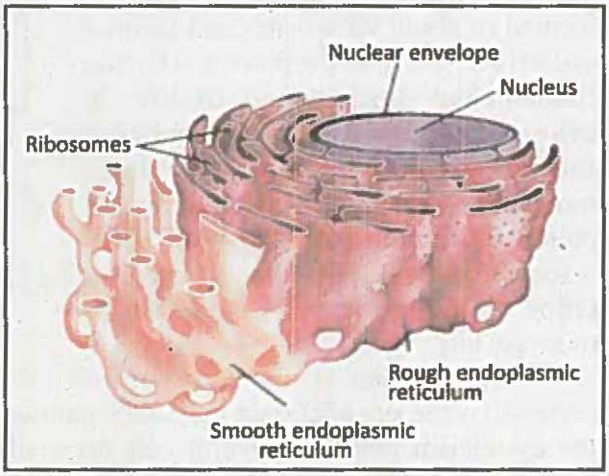


Fig 1.7 Endoplasmic reticulum

There are two morphological forms of endoplasmic reticulum; rough form with attached ribosome and a smooth form without ribosome. Rough endoplasmic reticulum (RER) are mostly present outside the nuclear membrane and thus involved in protein synthesis. After synthesis the proteins are either stored in the cytoplasm or exported out of the cell through

these channels.

The Smooth Endoplasmic Reticulum (SER) helps in metabolism of a number of different types of molecules particularly lipid synthesis. They also help to detoxify the harmful drugs. In some cells SER is responsible for the transmission of impulses, for example, muscle cells, nerve cells etc. In addition, SER play an important role in the transport of materials from one part of the cell to the other. It provides mechanical support to the cell so that its shape is maintained.

Do you know?

SER makes lipids from fatty acid & glycerol absorbed in the gut & passes them to the Golgi bodies for export. Hormone corticosteroids made in adrenal cortex & sex hormones testosterone, estrogen are also initiated by endoplasmic reticulum.

ii. Ribosomes

These are tiny cell organelles, about 20 nm in diameter and were first studied by Palade (1955). Eukaryotic ribosomes are composed of almost equal amount of RNA (ribonucleic acid) and protein; hence they are ribonucleoprotein particles.

The RNA present in ribosomes is ribosomal-RNA. Ribosomes exist in two forms; either freely dispersed in the cytosol or attached with RER as tiny granules and are the site of protein synthesis. Ribosomes are synthesized in nucleolus of the nucleus. An example of protein synthesized by free ribosomes is Haemoglobin in young RBCs. Each ribosome consists of two subunits; one large and one small as shown in fig 1.8.

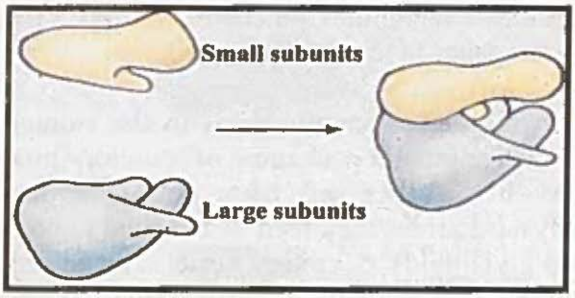


Fig 1.8 Ribosomes

Sedimentation has revealed two basic types of ribosomes called 70S (50Sand 30S) and 80S(60S and 40S) ribosomes (S = Svedberg unit used in ultracentrifugation). The 70S ribosomes are found in prokaryotes while slightly larger 80S in eukaryotes. The two subunits on attachment with each other require Mg^{++} ions. The ribosomes are attached to mRNA through small ribosomal units. A group of ribosomes attached to mRNA are called polysomes.

Tidbit

Due to small size ribosomes are the last organelle to be sedimented in a centrifuge requiring a force of 150,000 times gravity for 3 hours. Chloroplast and mitochondria contains 70S ribosomes, showing their prokaryotic origin.

iii. Golgi apparatus (Dictyosomes)

The Golgi apparatus was discovered by Camillo Golgi in 1898, using special staining techniques. This apparatus which was found virtually in all eukaryotes consists of stacks of flattened, membrane bounded sacs called cisternae. These cisternae together with associated vesicles are called Golgi-complex. It is a complex system of interconnected tubules around the central stack.

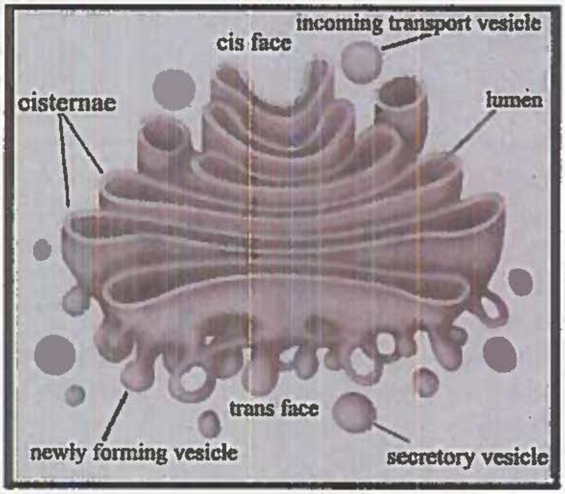


Fig: 1.9 Golgi Apparatus

The Golgi complex consists of units called dictyosomes. Each dictyosome is formed of bundles of curved and flattened cisternae, associated tubules and secretary vesicles. Dictyosome has two distinct faces. The proximal (cis) or forming face present close to nucleus and a distal (trans) or maturing face located towards the cell membrane. Vesicles and tubules pinched off from RER, flow, converge and fuse with the forming face to form new cisterna.

a. Functions of Golgi Apparatus

Golgi aaparatus helps in the storage of secretory products and in the modification and packaging of secretory products. In some cases polysaccharides may be synthesized from simple sugars in the Golgi apparatus. These polysaccharides may then be attached to proteins and lipids to form glycoproteins and glycolipids. Secretory vesicles produced by the Golgi apparatus may play an important role in adding surface area to the plasma membrane.

iv. Lysosomes

Lysosomes (lyso – splitting; soma – body) are cytoplasmic organelles found in most eukaryotes and are different from others cytoplasmic organelles due to their morphology. These were isolated as separate components for the first time by De Duve in 1949. They are surrounded by a single membrane and are simple sacs that contain very large variety of food digesting enzymes called hydrolases. Any foreign objects that gain entry with in the cell are immediately engulfed by the lysosomes and are completely broken down into digestible pieces. This process is known as phagocytosis. They are very abundant in those animal cells which exhibit phagocytic activity e.g neutrophils.

Lysosomes are bounded by single membrane and contain numerous hydrolytic and acid phosphatase enzymes. These enzymes are synthesized on RER and are further processed in the Golgi apparatus. The processed enzymes are budded off as Golgi vesicles and are called primary lysosomes. These contain those

enzymes which can digest the phagocytosed food particles.

During autophagy (self eating) some old worn out parts of the cell are also digested. In this way, materials of cell may be recycled and cell may be renewed. Their enzymes can also result in degeneration of cell, as may occur during the developmental processes.

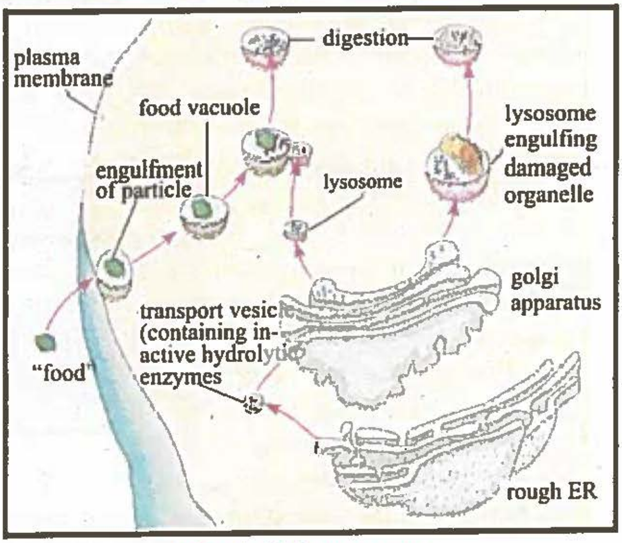


Fig: 1.10 Lysosomes

a. Malfunctioning of Lysosomes

Several congenital diseases have been found to be due to accumulation of substances such as glycogen or various lipids within the cell. These are also called storage diseases and are produced by a mutation that affects one of the lysosomal enzymes involved in the catabolism of certain substances.

For example, in **glycogenosis type II** disease, the liver and muscles cells appear filled with glycogen with in membrane bound organelles. In this disease, an enzyme that converts glycogen to glucose, is absent. Similarly **Tay-Sach's** disease is involved in the catabolism of lipids. Accumulation of lipids in brain cells lead to mental retardation and even death.

v. Peroxisomes and Glyoxisomes

The peroxisomes are small sub-cellular bodies approximately 0.5*um* in diameter, surrounded by membranes and found in a great variety of organisms,

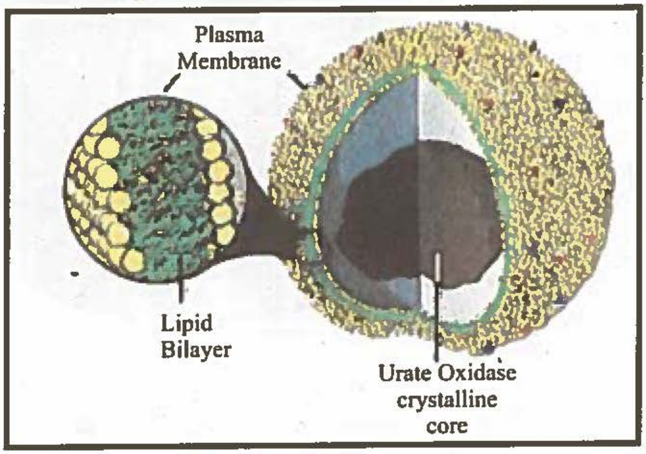


Fig 1.11 Peroxisomes

including plants and animals which are also called microbodies. In animals they are most common in liver and kidney cells. They are similar to lysosomes, but they are somewhat more dense and have different enzyme systems. For example, the enzymes of peroxisomes are known to break down hydrogen peroxide into oxygen and water, protecting cells from its corrosive effects. In the leaves of green plants, photorespiration may occur in peroxisomes.

Tidbit

Glyoxisomes only present during a short period in the germination of the lipid rich seed (castor oil seed) and is absent in lipid poor seed such as pea.

Glyoxisomes are present only in plant cells It contains a number of enzymes including glycolic acid oxidase and catalase .These organelles are most abundant in plant seedlings. The primary activity of the glyoxisomes is the conversion of fatty acids to carbohydrates. In lipid rich seeds such as soyabeens, glyoxisomes provide sites for the breakdown of lipids. These organelles are absent in seeds poor in lipid.

vi) Cytoskeleton

Koltzoff in 1928, by his microscopic studies suggested the existence of an organized fibrous network of skeleton in the cytoplasm of eukaryotic cells. Later on, Cohen (1977) confirmed the views of Koltzoff, by his electron microscopic studies.

According to Cohen, the cytoplasm of eukaryotic cells contains a cytoskeletal network of different types of microtubules, microfilaments and intermediate filaments.

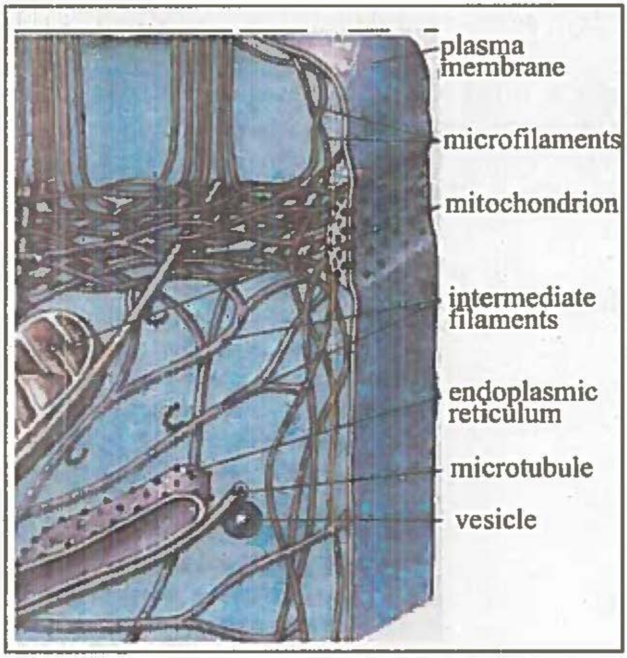


Fig 1.12 Cytoskeletal network of different types of microtubules, microfilaments and intermediate filaments

The main proteins that are present in the cytoskeleton are tubulin (in microtubules), actin, myosin, tropomyosin and others which are also found in muscles. Several cell organelles are derived from special assemblies of microtubules, e.g. cilia, flagella,

basal bodies and centrioles. Cyclosis and amoeboid movements are because of microfilaments, where as intermediate filaments are involved in determination of cell shape and integration of cellular components.

a. Microtubules

These are long, unbranched slender tubulin protein structures. One very important function of microtubules is their role in the assembly and disassembly of the spindle structures during cell division.

b. Microfilaments

These are considerably more thin cylinders made up of contractile actin proteins, linked to the inner face of the plasma membrane. They are involved in cyclosis.

c. Intermediate filaments

They have diameter in between those of microtubules and microfilaments. They help in maintaining the cell shape.

vii. Centrioles

Animal cells, cells of some microscopic organisms and lower plants for example mosses, liverworts etc. contain two centrioles located near the surface of the nucleus. These are small hollow cylinders (about 0.3-0.5 μm long & about 0.2 μm in diameter) that occur in pair.

In cross section each centriole consists of cylindrical array of nine microtubules. However each of the nine microtubules is further composed of three tubules (fig 1.13).

The two centrioles are usually placed at right angle to each other. Just before cell division, its centrioles duplicate and one pair migrates to the opposite side of the nucleus. The spindle fibers formation takes place by using centrioles as MTOCs (microtubule organizing center) located outside the nucleus. They are absent in higher plants. Centrioles play an important role in the location of furrowing during cell division and in the formation of cilia and flagella.

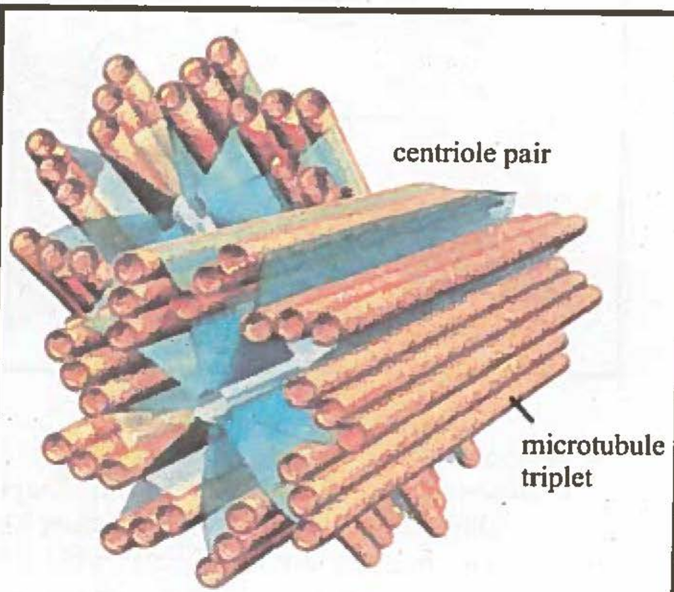


Fig 1.13 Centrioles

viii. Cilia and Flagella

Although cilia and flagella are the same, they were given different names before their structures were studied. Typically, cells possess one or two long flagella, whereas ciliated cells have many short cilia. For example, the mammalian spermatozoon has a single flagellum, the unicellular green alga *Chlamydomonas* has two flagella, and the unicellular protozoan *Paramecium* is covered with a few thousand cilia. Ciliary and flagellar beating is characterized by a series of bends, originating at the base of the structure and propagated toward the tip. Virtually all eukaryotic cilia and flagella are remarkably similar in their organization, possessing a central bundle of microtubules, called the axoneme, in which nine outer doublet microtubules surround a central pair of singlet microtubules. The bundle of microtubules comprising the axoneme is surrounded by the plasma membrane.

Tidbit

In higher plants, cells seem to organize microtubules at sites distributed all around the nuclear envelope. However, they do use the special tubulin (gamma tubulin) to nucleate microtubules, just like the centrioles do in animal cells.

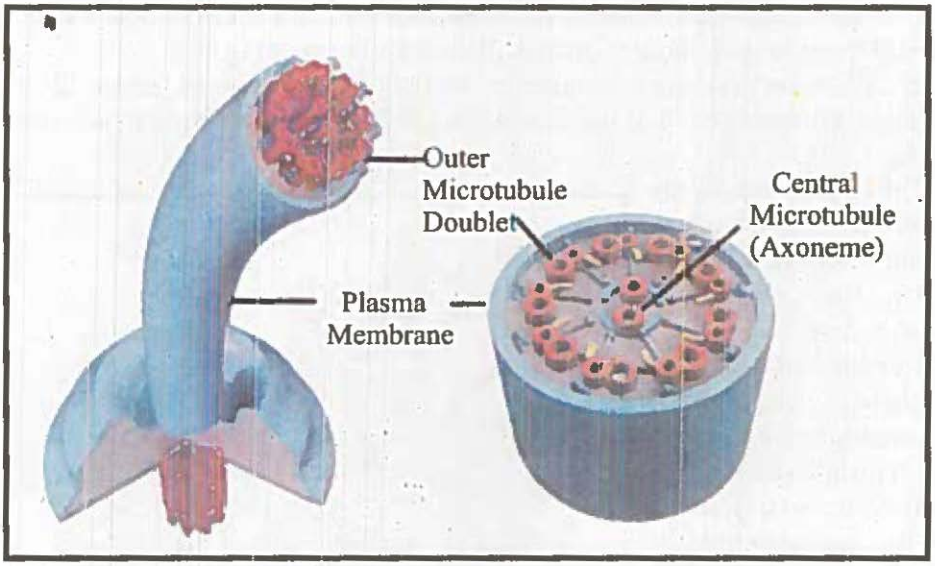


Fig 1.14 Internal organization of cilia

ix. Mitochondria

Mitochondria are found with in the cytoplasm of all eukaryotic cells, although in highly specialized cells such as mature RBCs, they may be absent. They were first seen as granules in muscle cells in 1850. They are known as the power house of the cell. Under the electron microscope, mitochondria appear to be vesicles, rods or filaments and also show complex morphology.

Although their number, shape and internal structure vary widely, a mitochondrion is bounded by two membranes, the outer one is smooth, while the inner membranes form infolding into the inner chamber called mitochondrial matrix. These in folds are called cristae (sing: crista). The membranes have the same chemical nature as that of cell membrane. The presence of **ribosomes** and **DNA** inside mitochondria indicate that some proteins are synthesized in it, so it is a **self replicating** organelle.

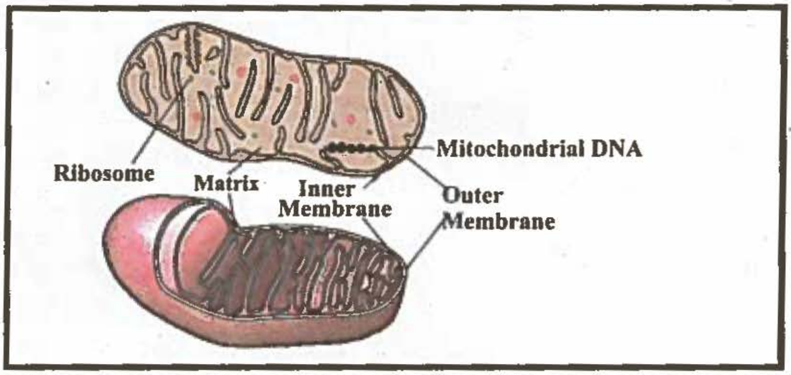


Fig: 1.15 Mitochondrium

The inner surface of cristae in the mitochondrial matrix has small knob like structures known as elementary particles (F_0 , F_1 particles). As mitochondrion is a site for all the reactions of aerobic respiration. Its matrix contains a large number of oxidative enzymes, co-enzymes, organic and inorganic salts, vital for aerobic respiration (Krebs cycle, Fatty acid metabolism etc). As a result of these metabolic processes the energy extracted from the organic food is transformed into energy rich compounds ATP (adenosine tri-phosphate) and in turn this energy is provided to the cells on demand.

x. Plastids

Membrane bounded, mostly pigment containing bodies present in the cell are called plastids. Plastids are the unique organelles found only in plant cells. There are three main types of plastids: a) Chloroplasts b) Chromoplasts c) Leucoplasts

a. Chloroplasts

In photosynthetic plant cells, these are membrane bounded structures containing a green pigment, chlorophyll. Chlorophyll is an organic compound which helps the cell to absorb sunlight and utilize it to manufacture food.

Chloroplasts vary in their shape and size with a diameter of about 4-6 µm. Under electron microscope they appear to be heterogeneous structures with small granules known as grana embedded in the matrix. Chloroplast shows three main components, the envelope, stroma and the thylakoid (fig 1.16). The envelope is

formed by a doubled membrane, while stroma covers most of the volume of the chloroplast. Stroma is a fluid which surrounds the thylakoids. It contains proteins, some ribosomes and a small circular DNA. It is in this part of the chloroplast where carbondixoide is fixed to manufacture sugars.

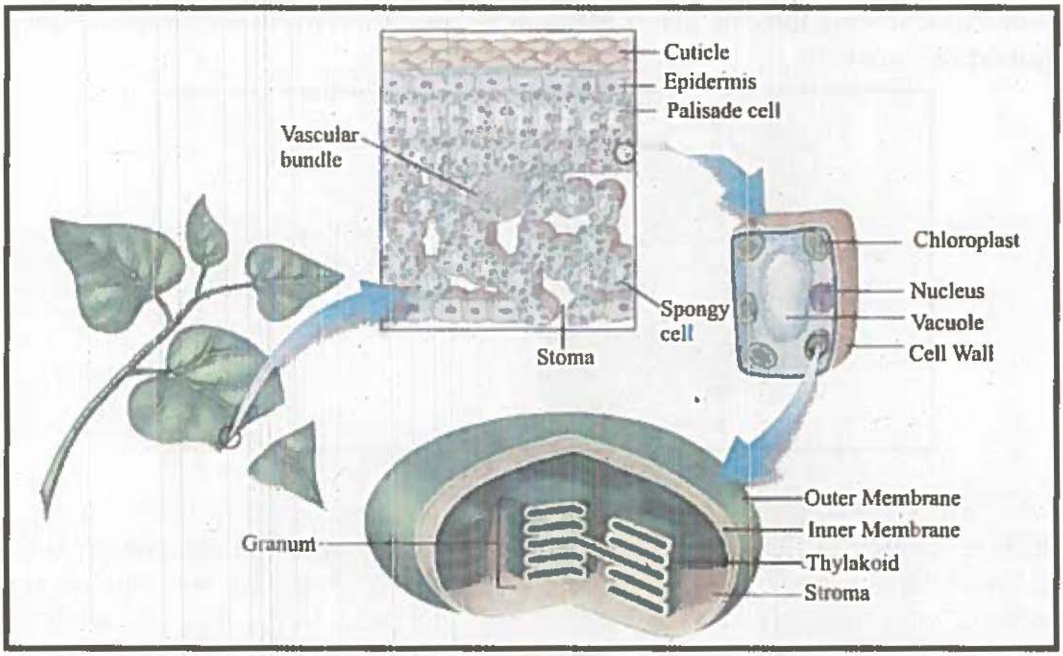


Fig 1.16 Location and structure of Chloroplast

Thylakoids are the flattened vesicles which arrange themselves to form grana. A granum appears to be a pile of thylakoids stacked on each other like coins. On average there are 50 or more thylakoid piled to form one granum. On the layers of the thylakoids, chlorophyll molecules are arranged and that is why granum appears to be green. Each granum is inter-connected with other by the non green part called intergranum. Chloroplasts are also self replicating organelle like mitochondria.

b. Chromoplasts

Chromoplasts impart colour to the plant parts other than green. They are present in the petals of the flower and in the ripened fruits. They help in pollination and dispersal of seeds.

c. Leucoplasts

Leucoplasts are colorless. They are triangular, tubular or of some other shape. They are mostly found in the underground parts of the plants and store food.

xi. Nucleus

Presence of cell nucleus was reported in 1838 by Robert Brown. Its early

discovery was due to its prominence in many cells, where it stands out as slightly darker than the surrounding cytoplasm. They are typically about 10 μm in diameter.

It is one of the most important organelle because it controls all the metabolic activities and has the genetic information in the form of chromosomes and DNA. They may be irregular or spherical in shape.

Generally, the cells having one nucleus are called mono-nucleate, those with two nuclei are bi-nucleate and with more than two nuclei are said to be multi-nucleate.

Parts of Nucleus: Nucleus consists of the following parts:

a. Nuclear membrane
b. Nucleolus
c. Nucleoplasm
d. Chromosomes

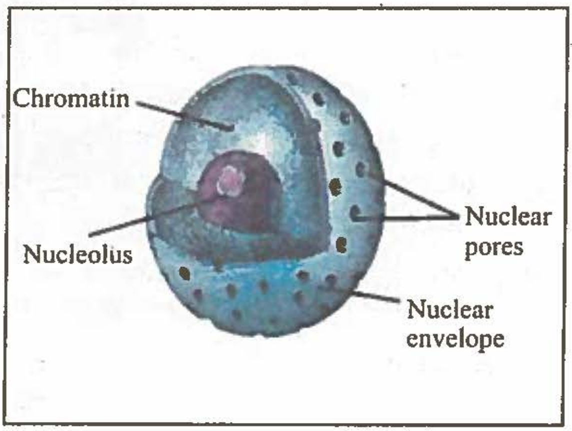


Fig: 1.17 Parts of a nucleus

a. Nuclear membrane

The outer membrane of the nucleus is the nuclear membrane which separates the nucleus from the cytoplasm (eukaryotic cells). The nuclear membrane is actually the nuclear envelop, composed of two membranes. The outer membrane is continuous with the endoplasmic reticulum (RER), while the inner membrane encloses the nuclear contents. These membranes are not continuous, leaving certain pores at points, the nuclear pores. Nuclear pores allow the exchange of materials between the nucleus and the cytoplasm.

b. Nucleolus

It is darkly stained body within the nucleus and is without any membranous boundary to separate it from the rest of nuclear material. There may be one or more nucleoli in the nucleus. The rRNA (ribosomal RNA) is synthesized and stored in the nucleolus. It is composed of two regions; the peripheral granular area composed of precursor of ribosomal subunits, and the central fibrillar area consisting of large molecular weight RNA and rDNA.

c. Nucleoplasm

The nucleoplasm is a colloidal mixture of organic and inorganic salts and ions. It serves as a matrix in which nucleoprotein complex (chromatin) is suspended. It also serves as storage place for enzymes, raw material needed for DNA replication and synthesis of RNA.

d. Chromosomes

During cell division chromatin material is stained as dark thread like

structures known as chromosomes. Under the compound microscope chromosomes appear to be made up of arms and centromeres. Centromere is the place on the chromosome where spindle fibers are attached during cell division. Each chromosome consists of two identical chromatids held together at the point (Kinetochore) at centromere.

A chromosome is composed of DNA and proteins. All the information necessary to control the cell activities is located on the chromosomes (locus) in the form of genes, which are transferred from one generation to another. The number of chromosomes in all individuals of the same species remains constant generation after generation.

Diploid and Haploid Number of Chromosomes

The full number of chromosomes in normal body cells is diploid (2n) where as haploid (n) is the half number of chromosomes present in germ or gamete cells. For example, human sperms and eggs have 23 each and those of Drosophila have 4 each in sperms and eggs. So in this way after fertilization the number of chromosomes remains constant in the next generation.

For your information

Every species have a specific number of chromosomes in their cells.			
Man	46 (23 pairs)	**Frog**	26 (13 pairs)
Chimpanzee	48 (24 pairs)	**Drosophila**	8 (4 pairs)
Onion	16 (8 pairs)	**Potato**	48 (24pairs)
Garden pea	14 (7 pairs)	**Pigeon**	80(40 pairs)

1.5 Prokaryotic and Eukaryotic Cell

Biologists have divided cells into two types; prokaryotic and eukaryotic cells. The differences between these two types of cells are mainly based upon the structure of their nuclei. Eukaryotes have a very well defined nucleus, in which nuclear material is enclosed in doubled nuclear membrane. In prokaryotic cells, the genetic material and the chromatin network is without any nuclear membrane and is

directly submerged in the cytoplasm. Prokaryotes include bacteria and blue green algae, while eukaryotes include all other unicellular or multicellular organisms such as protists (amoeba, paramecium, and euglena etc), animals, plants and fungi.

Detailed studies show that prokaryotic cells generally lack many of the membrane bounded structures which are present in eukaryotic cells. For example, mitochondria, endoplasmic reticulum, chloroplasts, Golgi complex etc are absent in prokaryotes. Since there is no nuclear membrane a prokaryotic cell has no distinct nucleus and it DNA molecule is directly suspended in the cytoplasm. Prokaryotes have small sized ribosomes i.e. 70S. In prokaryotes mitosis is missing and the cells divide by binary fission.Because of the simpler structure of prokaryotes, it was widely accepted for a long time that prokaryotic cell represents a more primitive stage of evolution than eukaryotes. Perhaps the most distinctive features of the prokaryotic cell is its cell wall, composed of polysaccharides chain bound covalently to shorter chain of amino acids forming peptidoglycan or murein.

Tidbit

Undifferentiated cells such as **egg** have about 30,000 pores per nucleus where as differentiated cells (**erythrocytes**) have only 3 to 4 pores per nucleus.

The entire cell wall is often regarded as a single huge molecule or molecular complex called murein. The cell wall of plants (eukaryotes) is generally made of cellulose and is differently structured than that of a bacterium (prokaryotes).

1.5.1 Structure of Bacteria as a Model Prokaryote

Bacteria as mentioned earlier are prokaryotes. These are the smallest cellular organisms and are the most abundant in the universe. Bacteria along with cyanobacteria (blue green algae) which are included in kingdom prokaryotae are the only living prokaryotic organisms.

The cell wall of bacteria has murein (as mentioned earlier), it is rigid structure and determines the shape of the bacterium. It also protects the cells from osmotic lysis. Bacterial cell unlike eukaryotic organisms lacks discrete chromosome and nuclear membrane. The nuclear material (DNA) in bacterial cells occupies a position near to the center of the cell. This material is a single, circular and double stranded DNA molecule.

Bacteria only have ribosomes, composed of RNA and proteins. There are thousands of ribosomes in each healthy growing cell. Sexual reproduction in bacteria involves the exchange of DNA. This process occurs in three different ways:

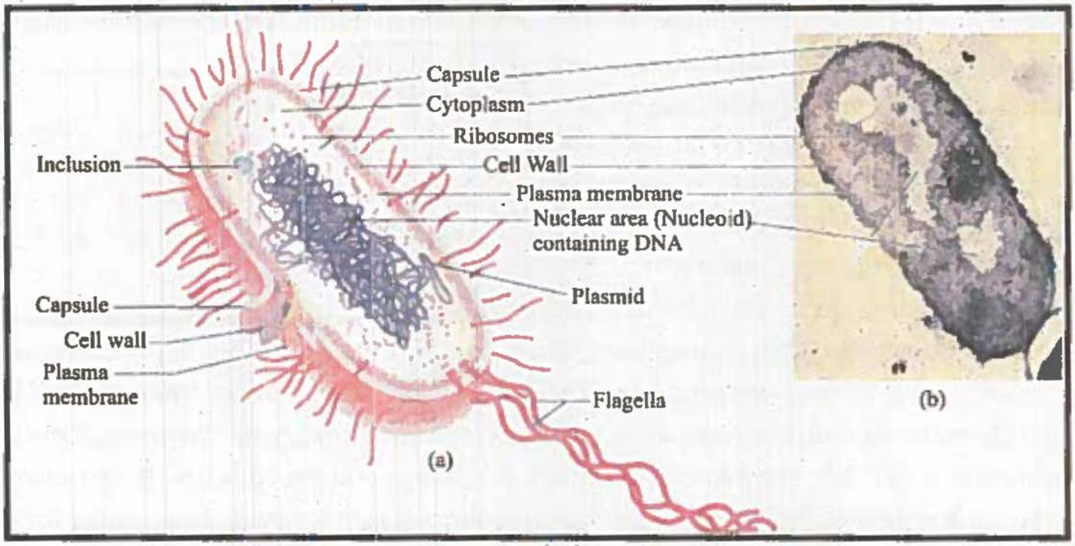


Fig: 1.18 Structure of Bacterial cell

Conjugation: In conjugation, DNA passes through an extension on the surface of one bacterium and travels to another bacterium. Bacteria essential exchange DNA via conjugation.

2. **Transformation**: In transformation, bacteria pick up pieces of DNA from their environment.

3. **Transduction**: In transduction, viruses that infect bacteria carry DNA from one bacterium to another.

Tidbit

Each one of us has with in our body ten times as many bacterial cells as we have cells of our own.

KEY POINTS

- Cell is the unit of structure and function of living organisms.
- The process by which various cell components can be isolated is called cell fractionation.
- The cell theory describes that all organisms are composed of one or more cells, the cell arise from pre –existing cells and the cell is the structural and functional unit of all organisms.
- The cell may be prokaryotic or eukaryotic. The prokaryotic cell lacks most of the membrane bounded organelles. The nuclear region in prokaryotic cell is called nucleoid.
- All cells are bounded by the plasma membrane. Cell wall is an additional covering in plant cells out side the plasma membrane.
- The model of plasma membrane which is accepted the world over is fluid mosaic model.
- Plasma membrane is a selectively permeable membrane.
- Cell wall in plants gives shape ,protection and support to the cell.
- Endoplasmic reticulum helps in the transport of materials between the cytoplasm and nucleus and also involved in the protein synthesis.
- Golgi apparatus is mainly concerned with storage of secretory products and are made up of vesicles arranged approximately parallel to each other.
- Lysosomes are bounded by a single membrane.
- Mitochondria are the energy producing organelles hence called powerhouses of the cell.
- Plastids are of three types i.e. chloroplast ,chromoplast and leucoplast.
- Microfilaments and microtubules give support ,shape and strength to the cell.
- Most animals cell contain a pair of centrioles lying at right angle to one another.
- The largest and the most conspicuous structure or cell organelle is the double membrane bounded nucleus.
- The two prominent structures present in the nucleus are chromosomes and nucleolus (nucleoli).

EXERCISE ?

A. Choose the correct answers in the following questions.

1. Which of the following is best suited stain in order to study chromosomes?
   - a. Iodine solution
   - b. Leishman's stain
   - c. Feulgen 's stain
   - d. Aniline blue

2. The 'Scavengers' or 'Digestive bags' of a cell are ____.
   - a. chromosomes
   - b. centrosomes
   - c. lysosomes
   - d. ribosomes

3. Following are the functions of cytoskeleton EXCEPT:
   - a. Maintaining cell shape
   - b. Movement
   - c. Contraction
   - d. Respiration

4. Identify the mismatch in the following pairs:
   - a. Mitochondria – cellular respiration
   - b. Lysosome- intra cellular digestion
   - c. Microfilament- cyclosis
   - d. Glyoxisome- deamination

5. The most prominent cell organelle of a bacterial cell other than DNA is:
   - a. Mesosome
   - b. Ribosome
   - c. Lysosomes
   - d. Nucleosome

6. The cell wall of prokaryotic cell (bacterial) is composed of :
   - a. Pectin
   - b. Lignin
   - c. Cellulose
   - d. Murein

7. The cell organelle in eukaryotic cell which is NOT bounded by the membrane is :
   - a. Lysosomes
   - b. Centriole
   - c. Peroxisomes
   - d. Mitochondrion

8. In which part of the chloroplast the fixation of CO_2 results in the formation of sugars?
   - a. Envelope
   - b. Stroma
   - c. Thylakoid
   - d. Intergranum

9. The organelle which is absent in animals cell:
   a. Plastids b. Centriole
   c. Lysomes d. Nucleolus

10. The special proteins which carry lipid –insoluble large molecules through pores of plasma membrane are called :
   a. Permeases b. Catalases
   c. Arginases d. Amylases

11. The membrane enclosed spaces of endoplasmic reticulum are called:
   a. Lamellae b. Cisternae
   c. Stroma d. Cristae

12. All of the following refers to lysosomes **EXCEPT**:
   a. Slightly larger than mitochondria
   b. Roughly spherical
   c. Single membrane bounded
   d. Contain powerful digestive enzymes

...mes are also called as:
   a. Peroxisomes b. Mesosomes
   c. Phagosomes d. Glyoxisomes

14. In the leaves of green plants, peroxisomes are the sites of:
   a. Respiration b. Photosynthesis
   c. Photorespiration d. Phototropism

B. Write short answers of the following questions.

1. List four main functions of a nucleus.
2. What do you know about peroxisomes?
3. Write two differences between rough endoplasmic reticulum and smooth endoplasmic reticulum.
4. What is cytoskeleton? Why it is consider to be important organelle in the cell.
5. Cell is called structural and functional unit of life. Justify the statement.
6. Why are chloroplast found only in plant cells?
7. What are the consequences of cell losing cell membrane?

C. Write the answers of the following questions.

1. Differentiate between a prokaryotic and eukaryotic cell.
2. Describe the fluid mosaic model of plasma membrane.
3. What do you know about Golgi apparatus. Describe its functions.
4. Explain critically the role of lysosomes in human body.
5. Write a note on cytoskeleton.
6. What do you mean by tissue culture? What are the main steps involved in the process of tissue culture?
7. How do the cell organelles work together to keep us alive.
8. Discuss how the structure of specialized animal cells is related to their functions?

Projects:

- Make a fluid mosaic model of plasma membrane.
- Take a material of your choice and measure the size of its cells by micrometry.
- Compare in tabular form, the functions of organelles with the processes occurring in animals and plants on a chart and share it in the class

Chapter

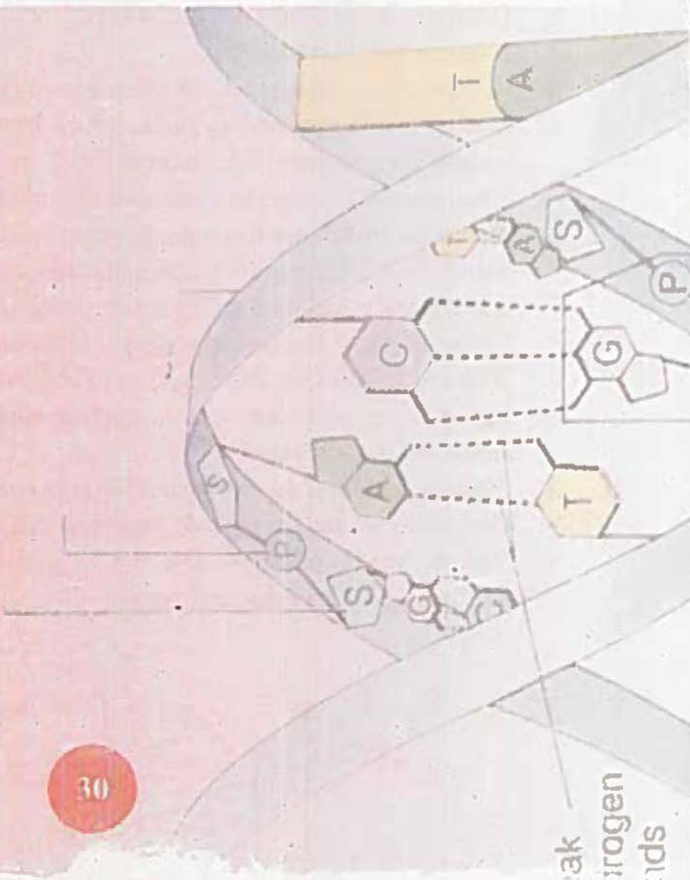
2

Biological Molecules

At the end of this chapter students will be able to:

- Introduce biochemistry and describe the approximate chemical composition of protoplasm.
- Distinguish carbohydrates, proteins, lipids and nucleic acids as the four fundamental kinds of biological molecules.
- Describe and draw sketches of the dehydration-synthesis and hydrolysis reactions for the making and breaking of macromolecule polymers.
- Explain how the properties of water (high polarity, hydrogen bonding, high specific heat, high heat of vaporization, cohesion, hydrophobic exclusion, ionization and lower density of ice) make it the cradle of life.
- Define carbohydrates and classify them.
- Distinguish the properties and roles of monosaccharides, write their empirical formula and classify them.
- Compare the isomers and stereoisomers of glucose.
- Distinguish the properties and roles of disaccharides and describe glycosidic bond in the transport disaccharides.
- Distinguish the properties and roles of polysaccharides and relate them with the molecular structures of starch, glycogen, cellulose and chitin.
- Justify that the laboratory-manufactured sweeteners are "left-handed" sugars and cannot be metabolized by the "right-handed" enzymes.
- Define proteins and amino acids and draw the structural formula of amino acid. Outline the synthesis and breakage of peptide linkages.
- Justify the significance of the sequence of amino acids through the example of sickle cell hemoglobin.
- Classify proteins as globular and fibrous proteins.
- List examples and the roles of structural and functional proteins.
- Define lipids and describe the properties and roles of acylglycerols, phospholipids, terpenes and waxes.

- Illustrate the molecular structure (making and breaking) of an acylglycerol, a phospholipid and a terpene.
- Evaluate steroids and prostaglandins as important groups of lipids and describe their roles in living organisms.
- Define nucleic acids and nucleotides.
- Describe the molecular level structure of nucleotide.
- Distinguish among the nitrogenous bases found in the nucleotides of nucleic acids.
- Outline the examples of a mononucleotide (ATP) and a dinucleotide (NAD).
- Illustrate the formation of phosphodiester bond.
- Explain the double helical structure of DNA as proposed by Watson and Crick.
- Define gene is a sequence of nucleotides as part of DNA, which codes for the formation of a polypeptide.
- Explain the general structure of RNA.
- Distinguish in term of structures and roles, the three types of RNA.
- Define conjugated molecules and describe the roles of common conjugated molecules i.e. glycolipids, glycoproteins, lipoproteins and nucleoprotein.



Introduction

All material things in this world are made up of chemical elements. These elements are composed of atoms. The atoms are joined together forming molecules and compounds. The bodies of living organisms are made up of some of these chemical elements. The most common elements in the bodies of living organisms are carbon, hydrogen, nitrogen, oxygen, phosphorus and sulphur. Of these, carbon, hydrogen and oxygen constitute about 95% of human body by weight. Other elements are present in small proportion. **Biochemistry** is the science of biology that deals with the structure, composition and function of molecules that are present in the bodies of living organisms and chemical processes occurring in them.

The bonding of hydrogen, oxygen, nitrogen and other atoms to carbon atom forms the compounds called organic compounds. The organic molecules play most important role that characterize the structure and function of the cell organelles. Carbon-carbon bonds make chain of carbon atoms which form the skeleton or backbone of large organic molecules. The chemical analysis of protoplasm shows that it is composed of two types of compounds, i.e. organic compounds and inorganic compounds. These compounds are present in somewhat different proportions in different organisms and even in different types of cells of the same organism. Water is the most abundant of all compounds of protoplasm. It forms almost three-fourth of the body by weight, next to water are proteins. Proteins are the most abundant organic compounds present in the cell. Proteins have structural functional roles in the cell. Other organic compounds include carbohydrates, lipids and nucleic acids. Enzymes which are proteins in nature are also present. Hormones which play very important role and inorganic salts are present in small proportion.

A typical cell shows the following approximate percent composition of different compounds present inside it.

Table: 2.1 Approximate chemical percent composition of a Bacterial and a Mammalian animal) cell

Contents	Bacterial Cell	Mammalian Cell
Water	70	70
Proteins	15	18
Carbohydrates	3	4
Lipids	2	3
DNA	1	0.25
RNA	6	1.1
Enzymes, Hormones etc	2	2
Inorganic Ions etc	1	1

2.1 Fundamental Biological Molecules

There are four types of fundamental biological molecules present in protoplasm. These are carbohydrates, proteins, lipids and nucleic acids. These molecules are distinguished from one another on the basis of their chemical structures, composition and functions.

The organic molecules in living things such as fatty acids, amino acids, and carbohydrates have characteristic functional groups. These functional groups add to the diversity of organic molecules. Some functional groups are hydroxyl (alcohol) group, carboxyl (acid) group, aldehyde group, amine (amino) group etc.

Inorganic compounds such as water and inorganic salts are also present in the protoplasm. Water is vital for the life of living organisms and without sufficient quantity of water the protoplasm is unable to perform normal functions. Though inorganic salts are present in small quantities but they are important for most biochemical functions.

2.1.1 Condensation

Large organic molecules are called macromolecules or polymers. These are formed of particular types of small organic molecules or subunits called monomers. Two monomers join together when a hydroxyl group (OH) is removed from one monomer and a hydrogen (H) is removed from another. This is called **condensation** reaction (dehydration). In the process water molecule is removed e.g.

Amino acids join together to form a molecule called a dipeptide. The OH from the carboxyl group of one amino acid combines with a hydrogen atom from the amine group of the other amino acid to produce water (blue) in the equation below.

Fig: 2.1 Example of condensation reaction

Table: 2.2 Monomers of macromolecules (polymers) of some organic compounds

Polymers (Macromolecules)	Monomers (units)
Polysaccharides	Monosaccharides
Lipids	Glycerol and Fatty acids (for fats)
Proteins	Amino acids
Nucleic acids	Nucleotides

2.1.2 Hydrolysis (Hydro-water; lysis-splitting)

Polymers (macromolecules) are broken down into monomers by a process called hydrolysis. It is the reverse of condensation. In this process hydroxyl group from water attaches to one monomer and a hydrogen attaches to the other. This is called hydrolysis reaction because water *(hydro)* is used to break *(lyse)* a bond e.g.

$$\text{Sucrose} + \text{Water} \longrightarrow \text{Glucose} + \text{Fructose}$$

Both condensation reactions and hydrolysis need specific enzymes.

2.2 Biological Importance of Water

Water is essential for life. There is no existence of life without water. Allah the Almighty has created all living organisms from water. The bodies of living organisms contain 70 % to 90 % water. It is essential for existence of protoplasm because protoplasm cannot survive if its water content is reduced as low as 10 percent. Because of its immense importance water is present in sufficient amount in most of places on earth. The chemical and physical properties of water are so designed that they are absolutely important for the vital processes of life.

a. Polar Nature of Water

Water is polar molecule. The oxygen end of the molecule is electronegative bearing a partial negative charge and the hydrogen end is electropositive bearing a partial positive charge. Water molecules are bonded to one another through hydrogen bonds. Hydrogen bonds are much weaker than covalent bonds but they still cause water molecules to remain attached together.

b. Universal Solvent

Due to polar nature of water it dissolves almost all types of polar substances and is therefore regarded as **universal solvent**. This facilitates chemical reactions both inside and outside the living cell. Water provides the medium for most chemical reactions in cells. For example when sodium chloride is put into water,the electronegative ends of water molecules are attracted to the sodium ions and the electropositive ends of water molecules are attracted to the chloride ions. As a result the sodium and chloride ions separate and dissolve in water. Water dissolves all minerals present in soil which are absorbed by plant roots and transported to other tissues.

c. Cohesive and Adhesive Force of Water

The water molecules remain attached together and do not separate because of hydrogen bonding. This develops cohesive force among them and therefore water flows freely without breaking apart. Water molecules also adhere (stick) to surfaces

It can fill a tubular vessel and still flows so that dissolved molecules are evenly distributed throughout a system.

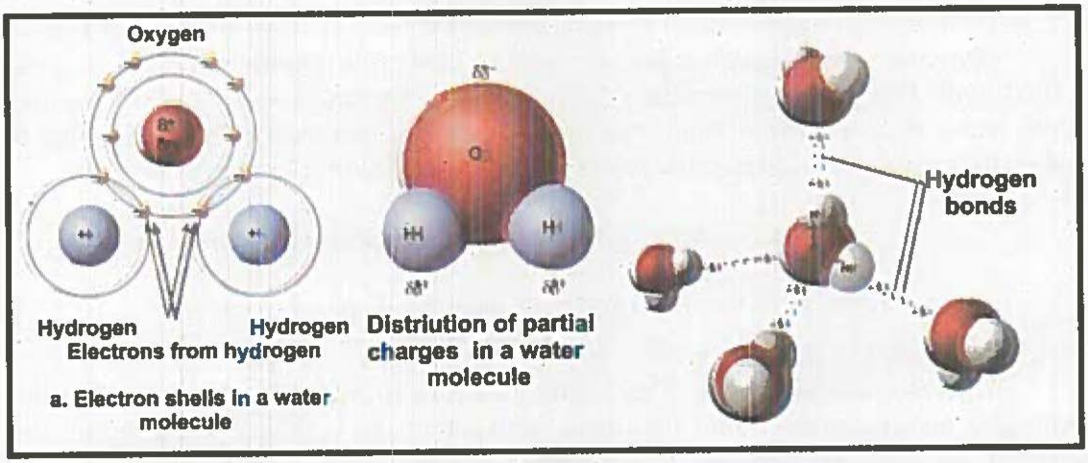


Fig:2.2 Chemical configuration of water

d. High Specific Heat and High Heat of Vaporization

Water has **high specific heat**. Specific heat is the amount of heat energy required to raise the temperature of one gram of water by one degree celsius. It means that water absorbs or releases large quantities of heat energy with little change in temperature. This is why the temperature of water rises and falls more slowly as compared to other liquids. This property helps the organisms to maintain body internal temperature and protect them from rapid temperature changes. Water also has high heat of vapourization. Heat of vapourization of water is the heat required to convert one gram of liquid water into vapours at its boiling point. High heat of vapourization helps animals and plants to get rid of excess body heat during sweating and transpiration respectively.

The presence of hydrogen bonds among the water molecules cause water to remain liquid rather than change to ice or steam. Without hydrogen bonds, water would boil at – 80 ^{0}C and would freeze at - 100 ^{0}C. In such conditions life for living organisms would become impossible.

Tidbit

The ice layer at surface acts as an insulator to prevent the water below it from freezing thus protecting the aquatic organisms from freezing.

e. Water Expands at Low Temperature

Water has a unique property, as it expands when temperature falls below 4 °C. Water is most heavy at 4 °C. Therefore ice (solid water) is less dense than liquid water and this is the reason that ice floats in liquid water. Water body freezes on the surface at low temperature.

f. Ionization of Water

Water molecules may ionize into hydrogen ions (H^+) and hydroxyl ions (OH^-). Very few molecules out of a very large number may ionize. The presence of ions is important for the normal functioning of enzymes.

2.3 Carbohydrates

Carbohydrates are polyhydroxy aldehydes or ketones or substances which yield such compounds on hydrolysis. Carbohydrates contain either aldehyde or ketone as functional groups attached to one of the carbon atoms. They also contain two or more hydroxyl groups. They are the most abundant organic biomolecules in nature. Carbohydrates are organic compounds that are mainly composed of carbon, hydrogen and oxygen. The name carbohydrates means that they are hydrates of carbon in which hydrogen and oxygen is present in the same ratio as in water that is 2:1. But now many carbohydrates are known that contain hydrogen and oxygen in different proportion. Examples of carbohydrates are glucose, sucrose, starch, cellulose etc. Carbohydrates are classified into three groups, i.e. monosaccharides, oligosaccharides and polysaccharides.

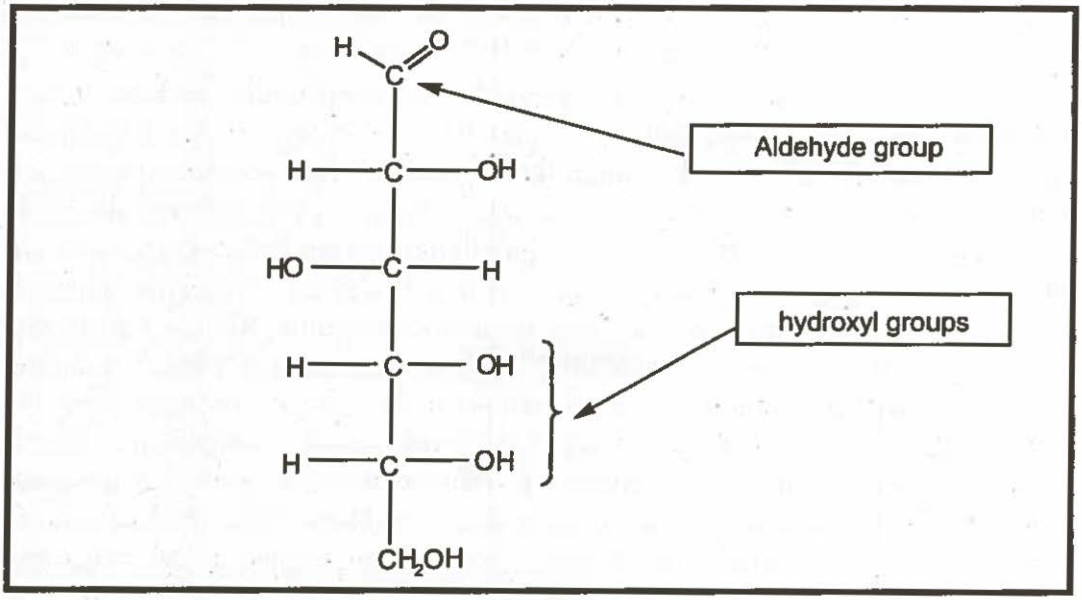


Fig: 2.3 Glucose containing aldehyde

2.3.1. Monosaccharides: (Mono = one; Saccharum = sugar)

Monosaccharides are simple sugars. They are not hydrolyzed (broken down by the addition of water) into more simple units. They are easily soluble in water. They are sweet in taste. They have empirical formula $(CH_2O)_n$ containing the same ratio of hydrogen and oxygen as in water, i.e. 2:1. They contain either aldehyde or keto group. They have carbon backbone that may contain from three to seven carbon atoms. They have names which end in –ose. Those with three carbon atoms are celled trioses, with four atoms-tetroses, with five atoms-pentoses, and so on.

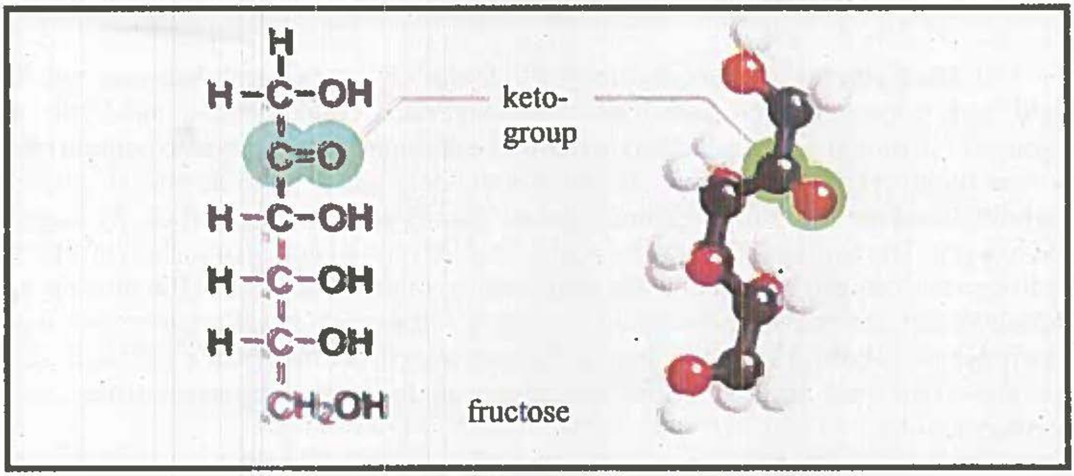


Fig: 2.4 Fructose containing keto group

Trioses are the simplest monosaccharides with three carbon atoms. Glyceraldehyde is triose with aldehyde group. Ribose is a pentose. It also contains aldehyde group. Ribulose is its ketonic form. Glucose, fructose and galactose are hexoses. They have the same empirical formula $(C_6H_{12}O_6)$ but different structural formula. Such molecules with the same empirical formula but different structures are called isomers. Glucose is aldehyde while fructose is ketone. Therefore glucose, fructose and galactose are isomers. They are inter-convertible. Ribose and glucose when put in water from ring structures. Monosaccharides are white crystalline powders. In stereoisomerism, the atoms making up the isomers are joined up in the same order, but still manage to have a different spatial arrangement. Optical isomerism is one form of stereoisomerism. **Optical isomers** are two compounds which contain the same number and kinds of atoms, and bonds (i.e., the connectivity between atoms is the same), and different spatial arrangements of the atoms, but which have non-superimposable mirror images.

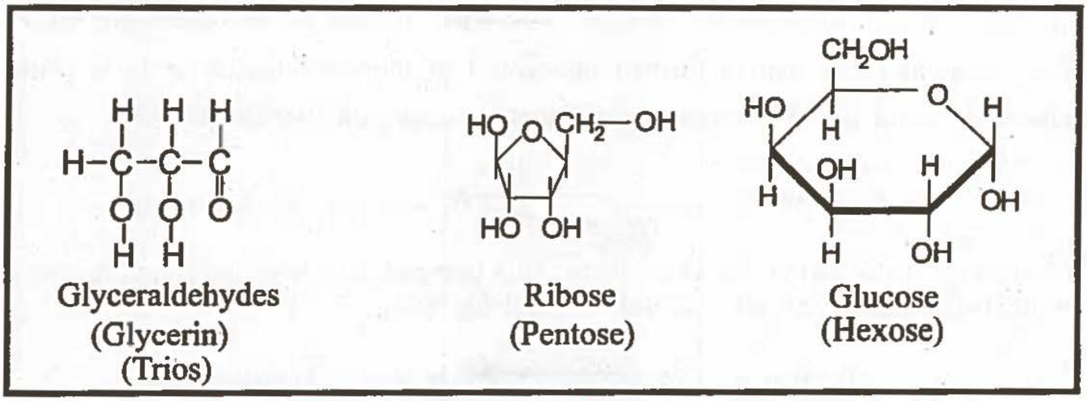


Fig: 2.5 Some examples of various types of Monosaccharides.

2.3.2 Oligosaccharides

Oligosaccharides are hydrolyzed to form (break up) from two to ten simple monosacharide units. The units or monomers are bonded together by glycosidic bonds. The oligosaccharides that are hydrolyzed into two simple units are called disaccharides, those hydrolyzed into three units are trisacchrides and so on.

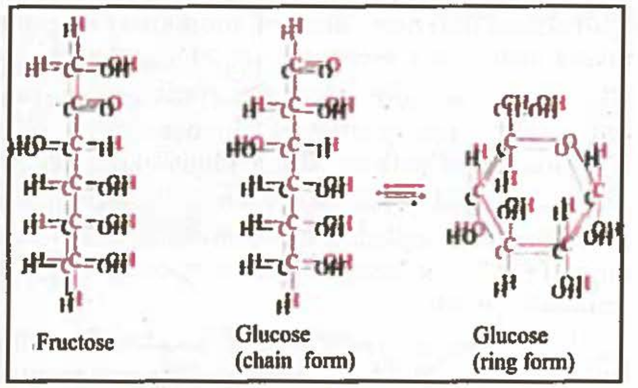


Fig: 2.6 Isomerism and stereoisomerism in glucose.

Disaccharides are the most common oligosaccharides.

Common disaccharides are sucrose, lactose and maltose. Sucrose is present in sugarcane and is hydrolyzed into glucose and fructose.

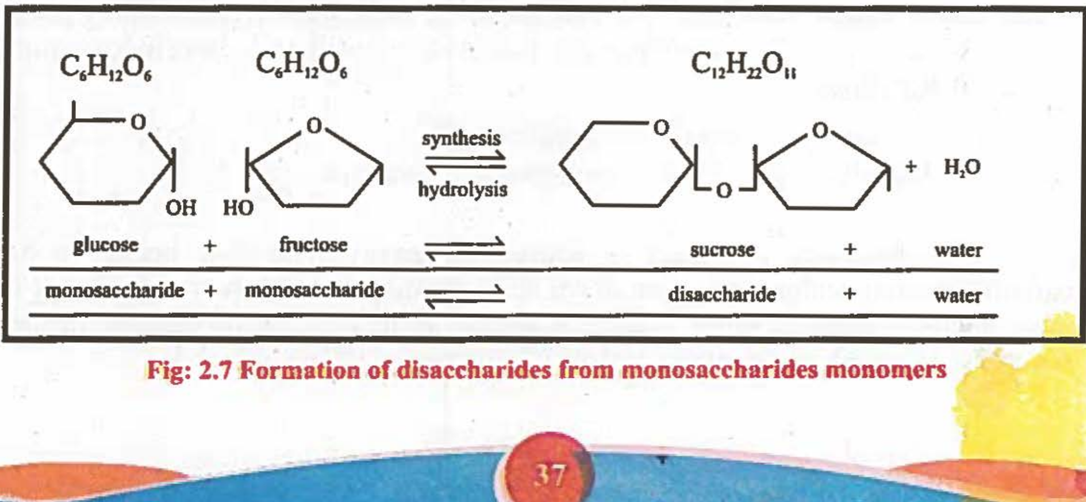


Fig: 2.7 Formation of disaccharides from monosaccharides monomers

$$\text{Sucrose} + \text{Water} + \text{Sucrase (enzyme)} \longrightarrow \text{Glucose} + \text{Fructose} + \text{Sucrase}$$

The covalent bond that is formed between two monosaccharide units is called glycosidic bond. Lactose is found in milk that contains galactose and glucose.

$$\text{Lactose} + \text{Water} \xrightarrow[\text{Lactase}]{\text{Hydrolase}} \text{Glucose} + \text{Galactose}$$

Maltose is disaccharide found in fruits. It is composed of two glucose units and is found in our digestive tract as a result of starch digestion.

$$\text{Maltose} + \text{Water} \xrightarrow[\text{Maltase}]{\text{Hydrolase}} \text{Glucose} + \text{Glucose}$$

2.3.3 Polysaccharides

Polysaccharides are polymers of monosaccharide units (monomers). They are hydrolyzed into more than ten monomers of glucose units. They are tasteless and are insoluble in water. Examples of polysaccharides are starch, glycogen, cellulose, chitin etc. Polysaccharides act as macromolecules (polymers) for the small carbohydrate units. Green plants prepare glucose during photosynthesis, which is immediately converted into starch. When plant needs glucose, starch is again converted into glucose. Starch is stored in plant cells. Starch is a polymer made up of many glucose units bonded together forming unbranched or branched chain. Glycogen is stored in animal cells. It is also a polymer made up of glucose monomers forming extensively branched chains.

Cellulose is another polysaccharide, formed of unbranched chain of glucose units. It is the building material of green plant cell walls and is probably the most abundant carbohydrate in nature. The bonds linking glucose units in a cellulose molecule are oriented differently from starch and glycogen. Cellulase refers to a group of enzymes which, acting together, hydrolyze cellulose. In human digestive system this enzyme is not present. Cotton fibers are example of cellulose. **Chitin** is a polysaccharide. It is found in the exoskeleton of arthropods such as crabs and insects. It is also a polymer of glucose but an amino ($-NH_2$) group is attached to each molecule. Like cellulose chitin is also not digestible.

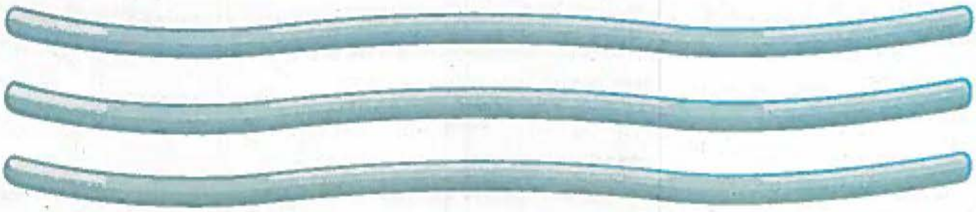
2.3.4 Functions of Carbohydrates

Carbohydrates perform various important functions:

Source of energy

Carbohydrates are used as source of energy. The C-H bonds in the carbohydratemolecules are broken down during respiration and the stored energy in these bonds is released which is made available to the cells for performing various functions. Human blood contains 100 mg of glucose per 100 ml of blood.

Cellulose fibers



Cellulose structure

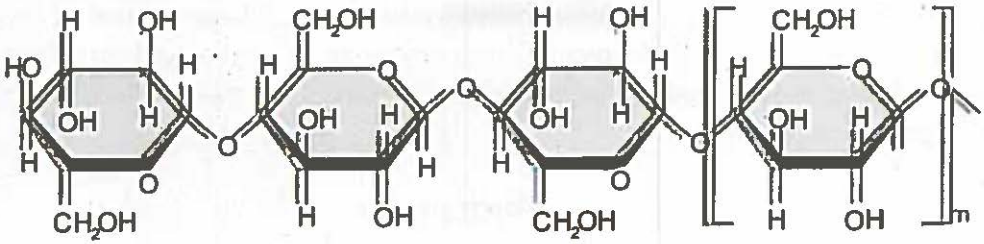


Fig: 2.8 Cellulose is a polysaccharide, formed of unbranched chain of glucose units.

Storage Molecules

Carbohydrates are stored in the cells as reserve food. Grapes contain as much as 27 % glucose. Honey contains large amounts of glucose and fructose. Some of these polysaccharides such as starch and glycogen excess amount of food is stored for future use.

For your information

The shape of a molecule affects lots of things besides its smell. Our bodies, for example, can only use right-handed sugar; left-handed sugar is indigestible. Amino acids, the building blocks of proteins, are almost all left-handed--our bodies can't manufacture proteins out of the right-handed version. (The cell walls of bacteria are one exception; they contain right-handed amino acids.)

Structural Building Materials

Cellulose a complex carbohydrate is the major structural component of cell walls of green plants. Similarly chitin another complex carbohydrate is the structural component of exoskeleton of arthropods.

2.4 Proteins

Proteins are the most abundant organic compounds of the cell. They play most important role in cellular functions. They contain elements carbon, hydrogen, oxygen and nitrogen. Some proteins also contain sulphur. Proteins are macromolecules (polymers) formed of units (monomers) called **amino acids**. A large number of amino acids are known. Of these, only twenty different types of amino acids combine in different number and different sequence forming hundreds and thousands of different types of protein molecules.

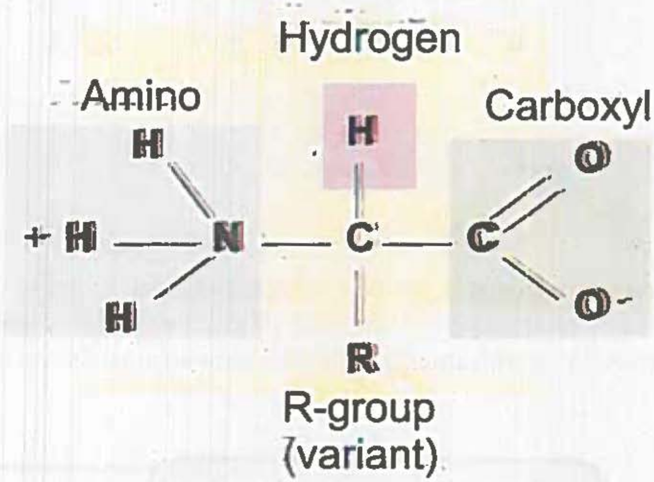


Fig: 2.9 Structure of Amino Acid

2.4.1 Structure of Amino Acids

Amino acids are carboxylic acids having amino groups. Each amino acid has a central carbon atom called alpha carbon. There are four different groups attached to the alpha carbon. These are amino group, carboxyl group, hydrogen of alpha carbon and R group. The former three groups attached to the alpha carbon are constant members and are present in all amino acids while the fourth one i.e. R-group is **variable**. It is either hydrogen or alkyl group. Due to this variable the amino acids are different from one another.

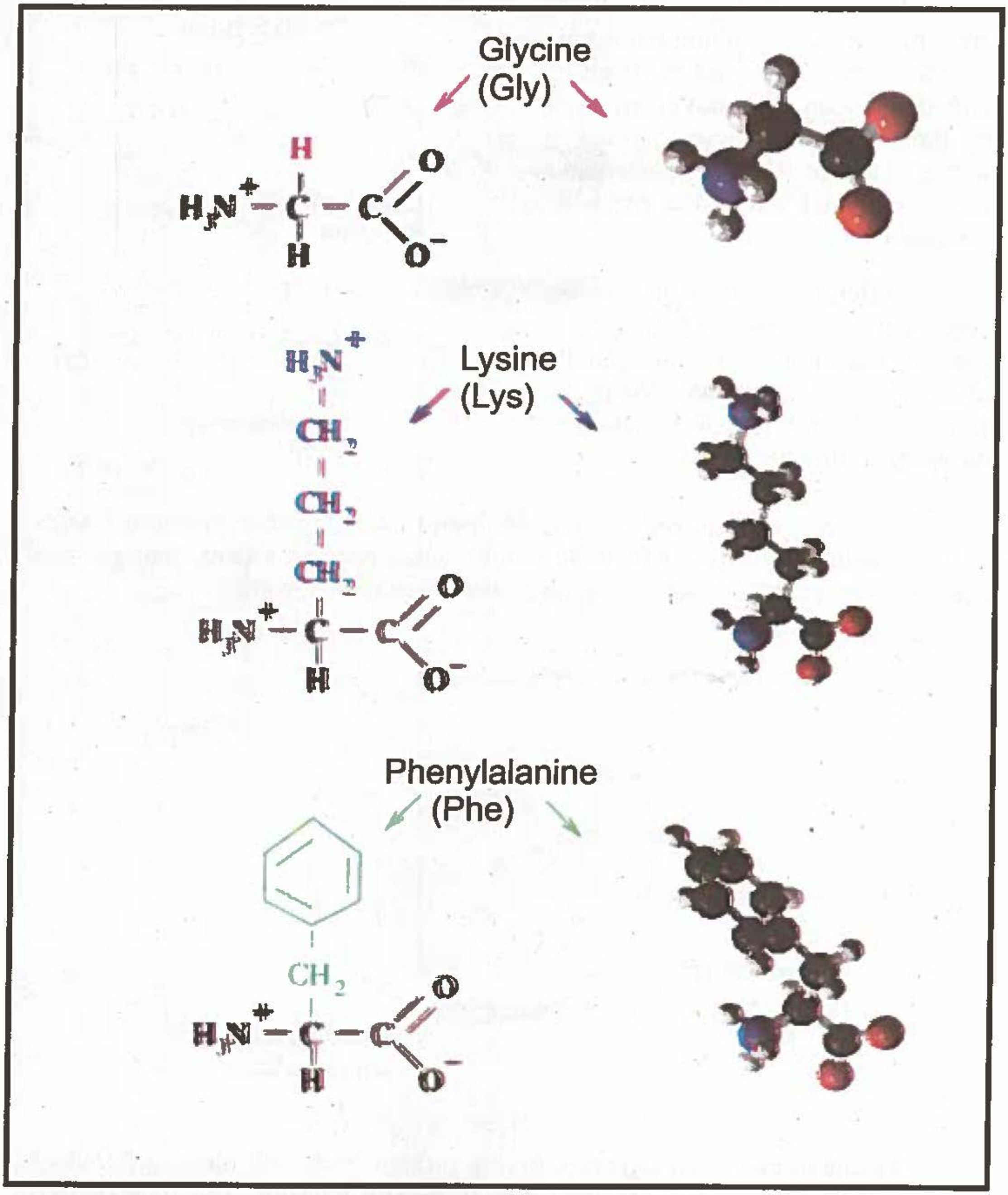


Fig: 2.10 Different types of amino acids

A bond called **peptide bond** links amino acids in a protein molecule to each other. The peptide bond is formed between an carboxyl group of one amino acid and amino group of another amino acid. This is condensation reaction in which one water molecule is formed.

Different amino acids can be joined together to make a protein. The order of the amino acids determines which protein will be made. When two amino acids are joined together, a **dipeptide** is formed.

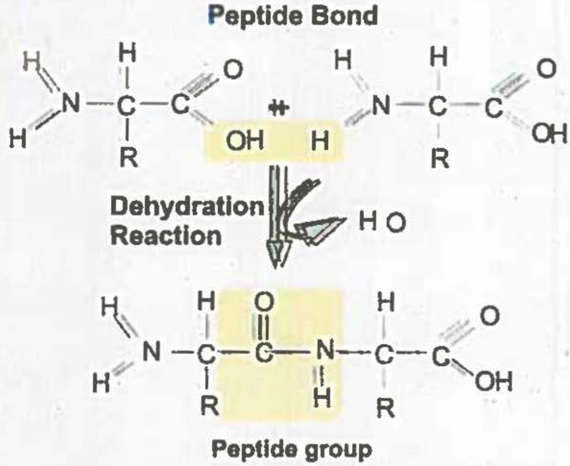


Fig: 2.11 Peptide bond between two amino

A special chemical bond called a **peptide bond** holds together two amino acids. Proteins usually consist of multiple amino acids, forming chains, that are held together by peptide bonds. For example, Haemoglobin and insulin.

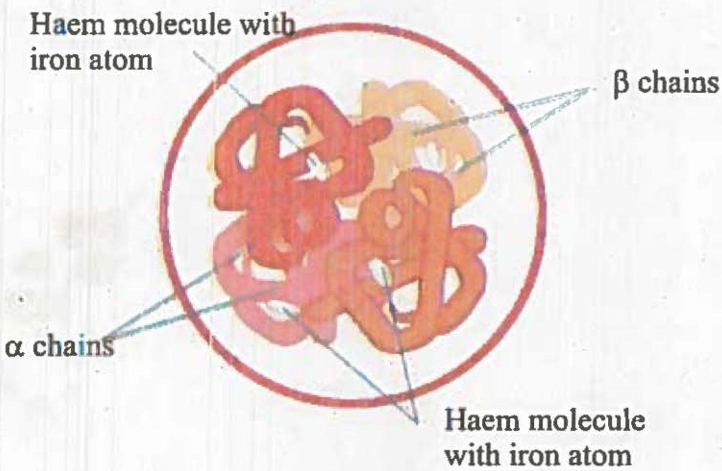


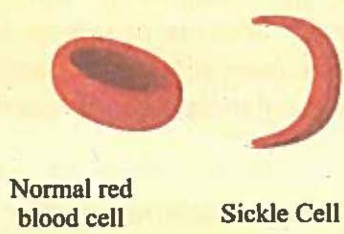
Fig: 2.12 Structure of Haemoglobin

Haemoglobin is an oxygen carrying protein in the red blood cells which consists of four polypeptide chains while an **insulin** molecule consists of two polypeptide chains. The number and sequence of amino acids in a protein molecule is highly specific for its normal function.

If an amino acid is not occupying its specific position in a protein molecule it will fail to perform its function. For example if one out of 574 amino acids in a haemoglobin molecule is not present in its specific position then haemoglobin changes its normal globular shape and becomes sickle-shaped. As a result the disc-shaped red blood cells also become sickle-shaped. In sickle cell haemoglobin molecule glutamic acid is replaced by valine. Such type of haemoglobin cannot perform its function and the person with sickle cell haemoglobin dies.The size of protein molecule depends upon the number and kinds of total amino acids present in the molecule.

For your information

Sickle cell anemia is a blood disorder that affects heamoglobin. Sickle cell anemia occurs when a person inherits two abnormal genes (one from each parent) that cause their RBCs to change shape. Instead of being flexible and disc-shaped, these cells are more stiff and curved in the shape of the old farm tool known as a sickle — that's where the disease gets its name. The shape is similar to a crescent moon. Red blood cells with normal haemoglobin(haemoglobin A, or HbA) move easily through the bloodstream, delivering oxygen to all of the cells of the body. Normal RBCs are shaped like discs or doughnuts with the centers partially "scooped out" and are soft and flexible. They can easily "squeeze" through even very small blood vessel.



2.4.2 Shape of Proteins

As regards the shape, proteins are classified into two types; fibrous proteins and globular proteins

a. Fibrous Proteins

The molecules of fibrous proteins are composed of one or more polypeptide chains, which are linearly arranged in the form of fibers. They are water insoluble. Some of these may form sheet-like structures. Examples of fibrous proteins are keratin found in hairs, nails, fur, outer skin, myosin present in muscle cells, collagen which is the most abundant protein in higher vertebrates found in skin, ligaments, tendons, bones and in the cornea of the eyes.

b. Globular Proteins

Globular proteins, as the name indicates, are globular or spherical in shape due to folding of polypeptide chains. They are usually water-soluble. Examples of

globular proteins are hemoglobin, albumen of egg white, enzymes, antibodies and the proteins of cell membranes.

2.4.3 Levels of Structure (Organization)

There are four levels of organization of protein molecules. This is because each type of polypeptide chain bends, folds and twists in particular way within a protein molecule. This gives protein molecule a characteristic structure that classifies protein into four different types. The primary structure is the sequence of the amino acids joined together by peptide bonds. Sanger in 1951 was the first person who determined the sequence of amino acids in insulin molecule.

A polypeptide chain having a linear sequence of amino acids is called primary structure. When a polypeptide chain of amino acids become spirally coiled, the structure is called a secondary structure of protein. When the secondary structure of protein is arranged into a three dimensional structure,it is called a tertiary structure. When two or more polypeptide chains are arranged into a large sized molecule, it is called a quaternary structure e.g. haemoglobin.

2.4.4 Functions of Proteins

Proteins perform the most important functions in the life of living organisms. Proteins are the structural and building materials of cellular membranes called lipo-protein membranes. All enzymes are proteins. They speed up biochemical reactions inside the body of living organisms. The digestive enzymes are important for the process of digestion. Without their presence food cannot be digested. Some hormones such as insulin are proteins which regulate biochemical processes. Myosin and actin fibers play an important role in the contraction of muscles and movements. Haemoglobin is oxygen-carrying protein of red blood cells. In animals' proteins form most structures such as skin, nails, hairs, claws, hooves etc. In plants proteins are stored in most seeds for the future need of the embryos e.g. bean, pulses, pea etc.

2.5 Lipids

Lipids are a group of different types of organic compounds. They contain carbon, hydrogen and oxygen. Other elements such as nitrogen and phosphorus may also be present in lipids. Most lipids are non-polar and are insoluble in water (hydrophobic). They are easily soluble in organic solvent such as ether, acetone, petrol, alcohol etc. They usually contain more carbon-hydrogen bonds and less oxygen as compared to carbohydrates. Lipids are classified into various types such as acylglycerol, phospholipids, waxes, terpenoids etc.

2.5.1 Acylglycerol

Acylglycerol are lipids which are composed of glycerol and fatty acids. The most common acylglycerol are triglycerides containing one glycerol molecule and three fatty acids. **Glycerol** is a three-carbon compound, to each carbon a hydroxyl group is attached. Hydroxyl groups are polar and therefore glycerol is soluble in water. The acid portions of three fatty acids react with three hydroxyl groups of the glycerol so that a triglycerid and three water molecules are formed. This reaction is condensation. The triglyceride molecule can be hydrolyzed into its components i.e. glycerol and three fatty acids.
Triglycerids are stored in animals as fats.

A **fatty acid** consists of a long hydrocarbon chain with a carboxyl (acid) group (-COOH) at one end. Most of fatty acids in cell contain 16-18 carbon atoms per molecule. Fatty acids may be saturated or unsaturated.

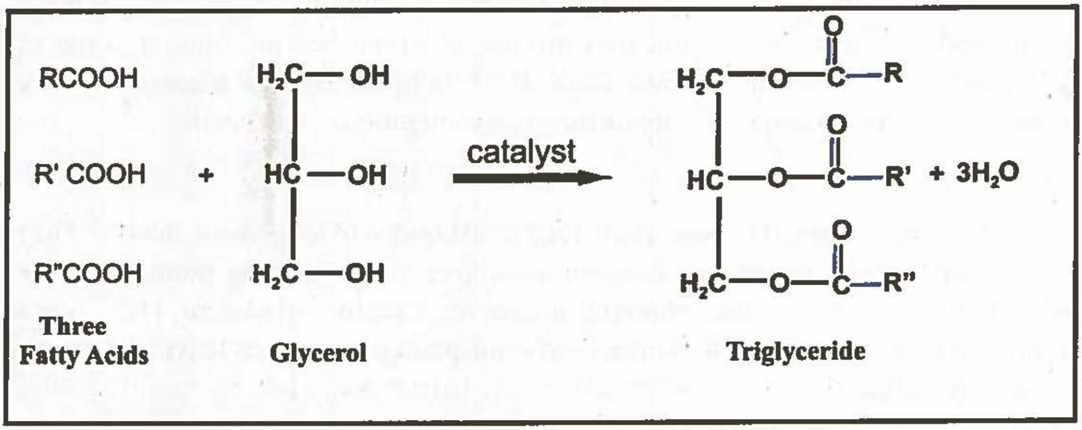


Fig: 2.13 Formation of Triglyceride from fatty acids and glycerol

Saturated fatty acids have no double bond between carbon atoms. Such molecules cannot accommodate any more hydrogen atoms if added to them. Acylglycerol with saturated fatty acids such as palmatic acids are called fats and are solid at room temperature. Saturated fatty acids are stored in animals as fats.

Unsaturated fatty acids have one or more double bonds between some carbon atoms (C=C). In such molecules the number of hydrogen is less than two per carbon atom. Any more hydrogen can be added to these molecules. Unsaturated fatty acids such as oleic acids are stored in plant seeds. Acylglycerol with unsaturated fatty acids are usually liquid at room temperature.

The triglyceroids have high caloric value and usually yield twice as much energy per gram as that of carbohydrate.

For your information

Ghee with saturated fatty acids is prepared from vegetable oil by passing hydrogen through it. Intake of ghee should be minimized as it may store in blood vessels reducing their flow capacity increasing risk of heart attack.

2.5.2 Phospholipids

Phospholipids are composed of one glycerol molecule, two fatty acids and one phosphoric acid molecule usually linked to some nitrogen group.

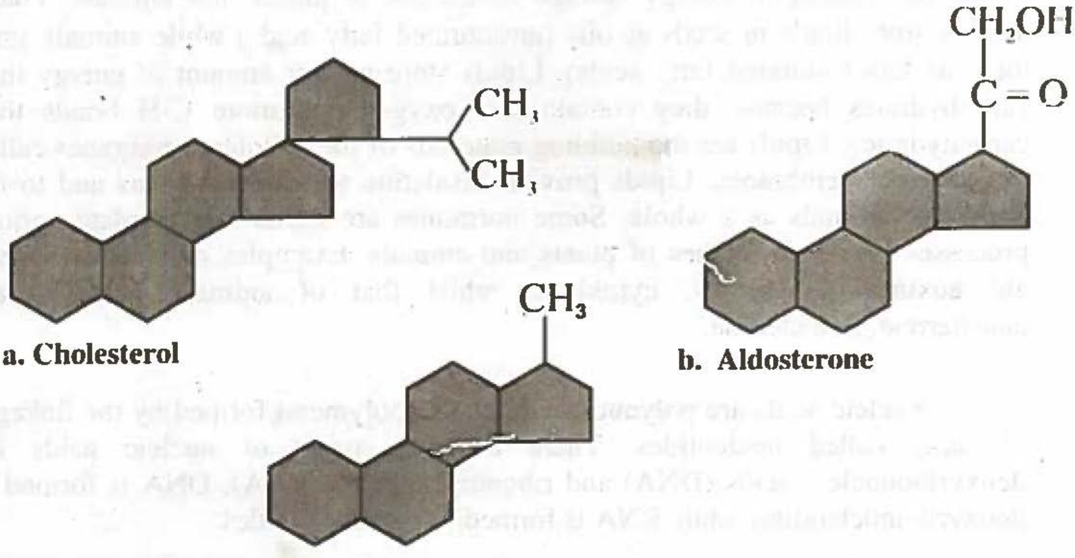
A triglyceride molecule is converted into phospholipid when a fatty acid is replaced by one phosphate. A phospholipid molecules has two parts. A phosphate head: It is polar and is therefore soluble in water or hydrophilic (hydro-water; philic-loving) and two hydrocarbon tails they are non polar and are insoluble in water or hydrophobic (hydro-water; phobos-fear). Phospholipids arrange themselves in a double layer in the presence of water in the plasma membrane of the cells.

2.5.3 Waxes

Waxes are formed by long chain fatty acid bonded to long chain alcohol. They are solid at normal temperature because they have a high melting point. They are hydrophobic. They are stable compound and are resistant to degradation. They form a waterproof layer (cuticle) on the surfaces of some plant parts such as leaves, fruits and in this way reduce the rate of water loss. Water barrier waxy layer generally covers bodies of some animals such as sheep and insects.

2.5.4 Steroids

Steroids are lipids that do not contain fatty acids. Each steroid is formed of a backbone of four fused carbon rings containing 17 carbon atoms. They differ from one another by the type of functional group attached. Different steroids have important functions in the bodies of humans and other animals. Cholesterol is a representative example of the steroids. It plays a role as an essential component in animal cell membranes. Cholesterol is also a precursor of all steroid hormones such as aldosterone, sex hormones and vitamin D. Aldosterone helps to regulate the sodium content of the blood. Sex hormones help to maintain male and female characteristics.



a. Cholesterol

b. Aldosterone

c. Testasterone

Fig: 2.14 Some representative examples of the steroids.

2.5.5 Terpenoids

Terpenoids are lipids that like the steroids do not contain fatty acids. They are lipid soluble and water insoluble substances. The terpenoids are formed of units called isoprenoid units. They join by the process of condensation and give rise to different types of compounds such as rubber, carotenoids, etc.

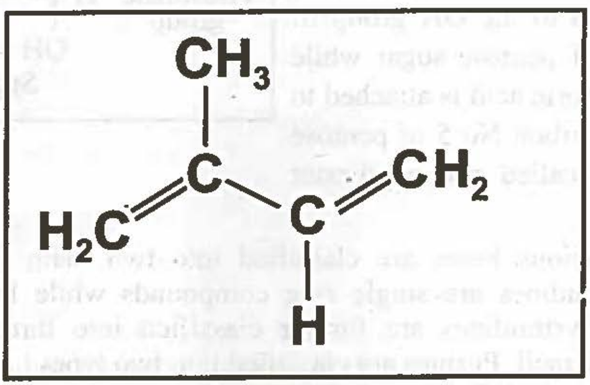


Fig: 2.15 An Isoprenoid units

2.5.6 Functions of lipids

Lipids are long-term energy storage molecules in plants and animals. Plants usually store lipids in seeds as oils (unsaturated fatty acids) while animals store them as fats (saturated fatty acids). Lipids store greater amount of energy than carbohydrates because they contain less oxygen and more C-H bonds than carbohydrates. Lipids are the building materials of the cellular membranes called lipo-protein membranes. Lipids provide insulation to various organs and to the bodies of animals as a whole. Some hormones are lipids that regulate various processes inside the bodies of plants and animals. Examples of plant hormones are auxins, gibberellins, cytokinins while that of animal hormones are aldosterone, testosterone.

2.6 Nucleic Acids

Nucleic acids are polynucleotide chain (polymers) formed by the linkages of units called nucleotides. There are two types of nucleic acids i.e. deoxyribonucleic acids (DNA) and ribonucleic acids (RNA). DNA is formed of deoxyribonucleotides while RNA is formed of ribonucleotides.

2.6.1 Nucleotides

In a typical nucleotide, the nitrogenous base is attached to carbon no. I of pentose sugar while phosphate group is attached to carbon No. 5 of the pentose sugar. The bond formed between phosphoric acids (H_3PO_4) and hydroxyl (OH) groups of pentose sugar is called ester linkage. In a polynucleotide chain one phosphoric acid is attached to the OH group of carbon No 3 of pentose sugar while another phosphoric acid is attached to OH group of carbon No 5 of pentose sugar. This is called phosphodiester linkage.

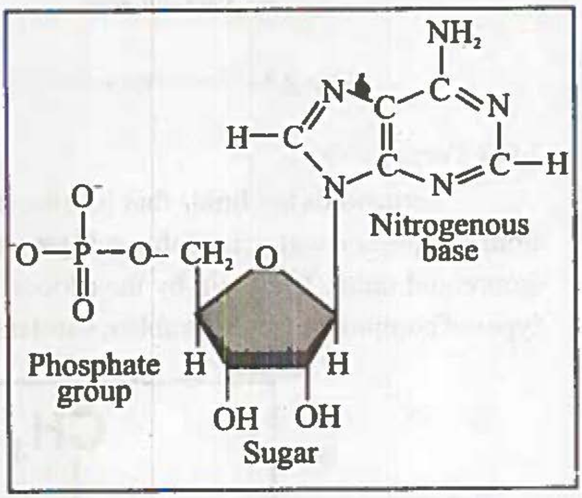
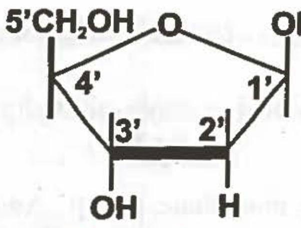
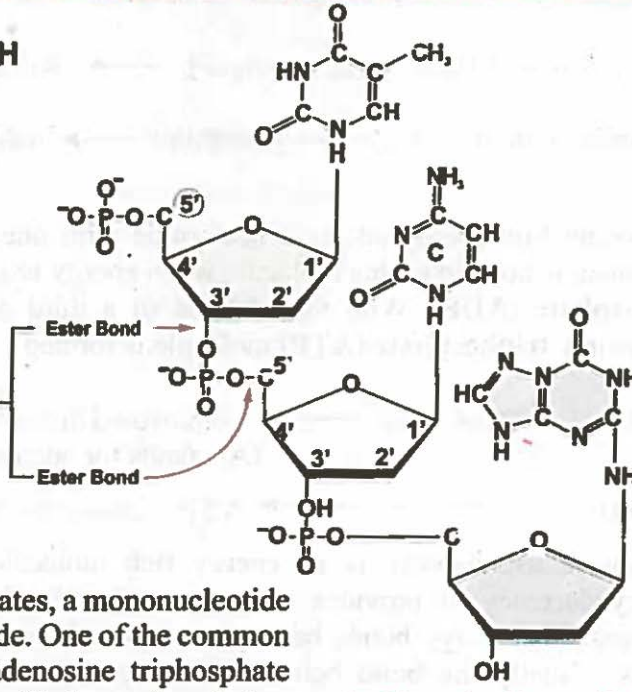


Fig: 2.16 Skeleton of a nucleotide

Nitrogenous bases are classified into two main types, Pyrimidines and Purines. Pyrimidines are single ring compounds while Purines are double ring compounds. Pyrimidines are further classified into three types, i.e. Thymine, Cytosine and Uracil. Purines are classified into two types i.e. Adenine and Guanine. Nucleotides are classified in to three types. These are mononucleotides dinucleotides and polynuceotides.



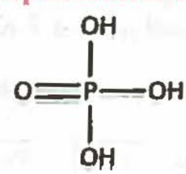
a. Deoxyribose



b. Phosphodiester linkage

2.6.2 Mononucleotides

As the name indicates, a mononucleotide exists as a single nucleotide. One of the common mononucleotide is the adenosine triphosphate (ATP). It is a nucleotide with three phosphates. Adenine base linked to pentose sugar (ribose) forms a structure called adenosine. When adenosine is bonded to a single phosphate it will form a nucleotide called adenosine monophosphate. This reaction needs energy.



c. Phosphoric acid

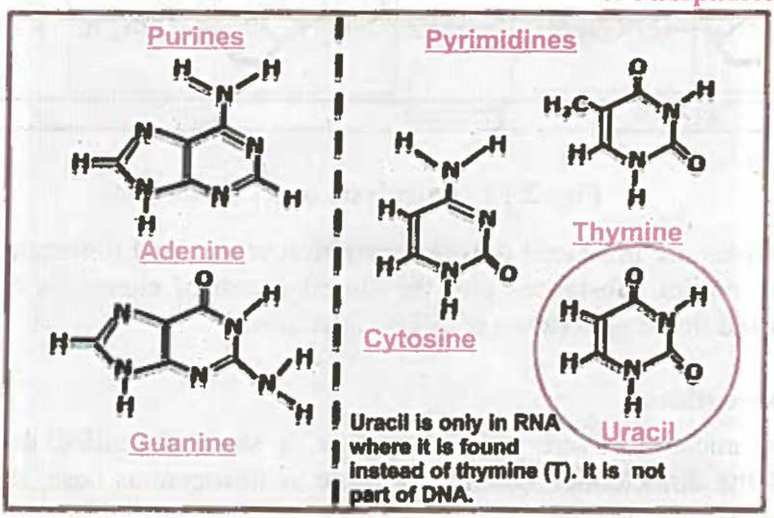


Fig: 2.17 Chemical structures

Adenine + Ribose (pentose sugar) ⟶ Adenine-Ribose (Adenosine)

Adenosine (Adenine-Ribose) + phosphate ⟶ Adenosine Monophosphate (AMP)

Adenosine Monophosphate is a nucleotide with one phosphate group. Another phosphate is bonded to this molecule when energy is supplied; it forms **adenosine diphosphate (ADP).** With the addition of a third phosphate and energy to it, **adenosime triphosphate** (ATP) molecule is formed.

AMP + Phosphate ⟶ Adenosine Diphosphate (ADP) " A-P~P "
(A- stands for adenosine; P for phosphate)

ADP + P ⟶ ATP (Adenosine Triphosphate) " A-P~P~P "

Adenosine triphosphate is an energy rich molecule and is commonly called energy currency. It provides energy to cells of all living organisms for their functions. The wavy bonds between the phosphate groups indicate high-energy bonds. Usually the bond between the second and third phosphate breaks up releasing the energy used by the cell. An ATP molecule is hydrolyzed into ADP and P and almost 7 Kcal energy is produced.

$$ATP + H_2O \longrightarrow ADP + P + 7.0 \text{ K Cal}$$

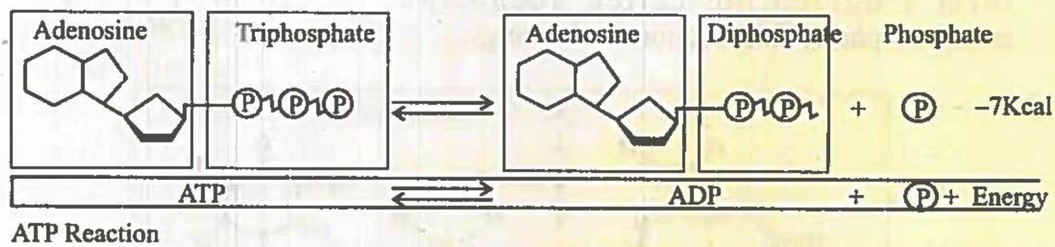


Fig: 2.18 Hydrolysis of ATP molecule.

ATP molecules are produced during respiration when food molecules are broken down into simpler substances and the stored chemical energy is released. This energy is used in the generation of ATP molecules.

2.6.3 Dinucleotides

When two nucleotides are linked together, a structure called dinucleotide is formed. If the dinucleotide contains adenine as nitrogenous base, then it will be called adenine dinucleotide.

The adenine dinucleotide in combination with different vitamins form important compounds called co-enzymes. Three important co-enzymes are NAD (Nicotinamide Adenine Dinucleotide), NADP (Nicotinamide Adenine Dinucleotide Phosphate) and FAD (Flavin Adenine Dinucleotide).

> **For your information**
>
> Nicotinamide is a vitamin called nicotinic acid (niacin). Flavin is also a vitamin called riboflavin (Vitamin B2).

These coenzymes can exist in two forms; a reduced and oxidized form. In the oxidized state they function as hydrogen acceptor. NAD and FAD are both active in the electron transport chain of respiration where they act as electron carriers. In the process they are alternately reduced and oxidized.

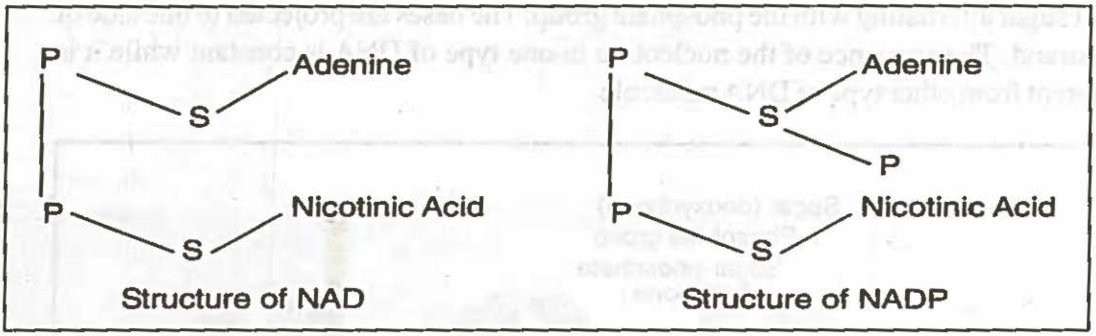


Fig: 2.19 Some examples of co-enzymes.

2.6.2 Polynucleotides (Poly:many)

When many nucleotides are linked together they form a structure called polynucleotide. DNA and RNA molecules are polynucleotide chains (strand). There are different types of RNA molecules, each type performs specific function under the instructions of DNA. Nucleic acids are of two types:

1. **DNA:** **Deoxyribonucleic Acid** – made of deoxyribonucleotides
2. **RNA:** **Ribonucleic Acid** - made of ribonucleotides

1. Deoxyribonucleic Acid (DNA)

In 1962 James Watson (b. 1928), Francis Crick (1916–2004), and Maurice Wilkins (1916–2004) jointly received the Nobel Prize in physiology or medicine for their 1953 determination of the structure of deoxyribonucleic acid (DNA). According to this model the DNA molecule is double helix. The double helix can be visualized as spiral stair case wound around a central axis. Watson and Crick suggested that base pair always consists of purine pointing toward pyrimidines,

keeping the molecule diameter at a constant 2nm. The base pair are flat with a distance of 0.34 nm between them.

DNA contains pentose sugar as deoxyribose. It is formed of four different types of nucleotides. These nucleotides are named after the base present in them they are: Adenine deoxyribonucleotide, Guanine deoxyribonucleotide, Thymine deoxyribonucleotide and Cytosine deoxyribonucleotide.

These four types of nucleotides are used as building blocks of DNA molecule. The nucleotides in the DNA molecule are bonded to one another in such a manner that the sugar of one nucleotide is linked to the phosphate group of the next one. In this way the nucleotides form a linear molecule called a strand in which the backbone is made up of sugar alternating with the phosphate group. The bases are projected to one side of the strand. The sequence of the nucleotide in one type of DNA is constant while it is different from other type of DNA molecule.

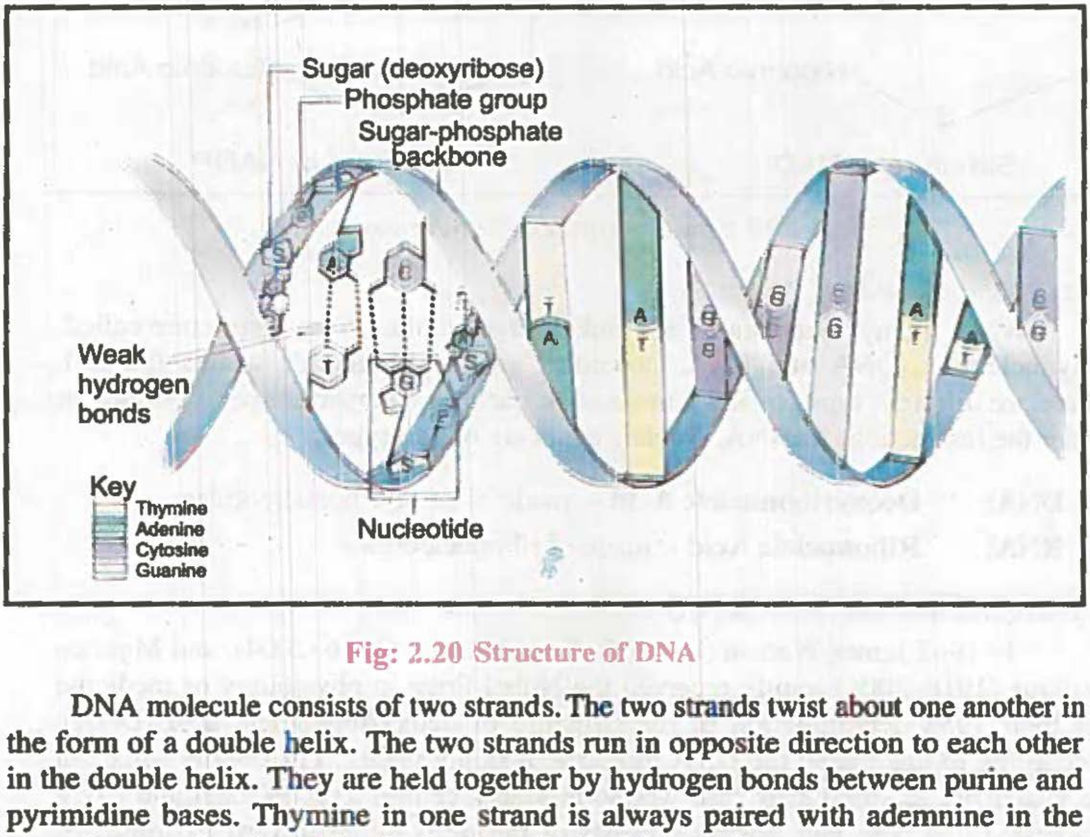


Fig: 2.20 Structure of DNA

DNA molecule consists of two strands. The two strands twist about one another in the form of a double helix. The two strands run in opposite direction to each other in the double helix. They are held together by hydrogen bonds between purine and pyrimidine bases. Thymine in one strand is always paired with ademnine in the opposite strand and guanine is always paired with cytosine.

There are two hydrogen bonds between adenine and thymine and three hydrogen bonds between guanine and cytosine.

2. Ribonucleic Acid

Ribonucleic acid is also a polymer of the nucleotides. Ribonucleic acid called RNA contains pentose sugar as Ribose. It is also formed of four different types of nucleotides. These nucleotides are named after the base present in them they are: adenine ribonucleotide, guanine ribonucleotide, cytosine ribonucleotide, uracil ribonucleotide. The nucleotides in the RNA molecule are linked in the same manner as in the DNA molecule. RNA is a single polynucleotide strand. In RNA the base uracil occurs instead of the base thymine.

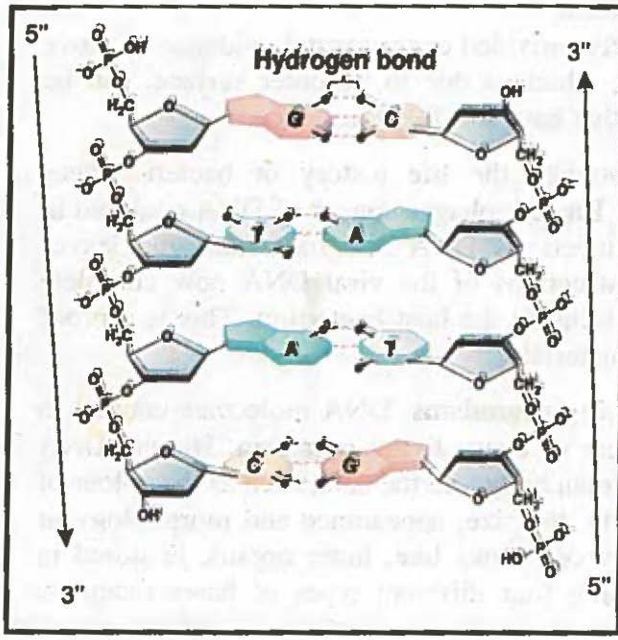


Fig: 2.21 Chemical structure of DNA

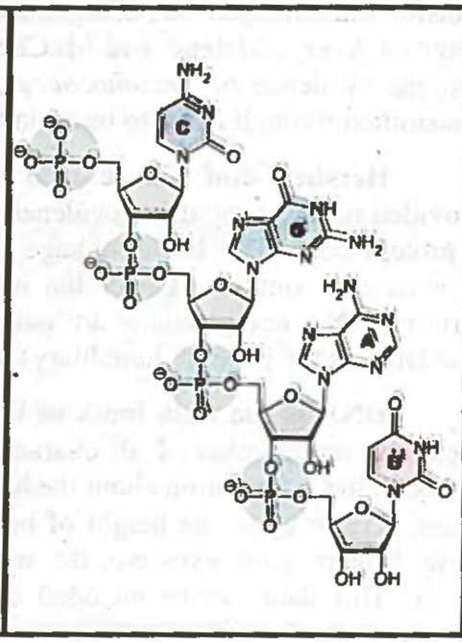


Fig: 2.22 Chemical structure of RNA

There are three types of RNA molecules; messenger RNA (mRNA), transfer RNA (tRNA) and ribosomal RNA (rRNA).

a. Messenger RNA (mRNA)

Messenger RNA carries messages from the DNA to the ribosome for protein synthesis.

b. Transfer RNA (tRNA)

Transfer RNA transfers the specific amino acid from the cytoplasm to the ribosome for protein synthesis.

c. Ribosomal RNA (rRNA)

Ribosomal RNA in combination with protein forms the body of the ribosome.

2.6.3 DNA as Hereditary Material

Chromosome is composed of DNA and proteins. Biologists conducted experiments and proved that DNA is the genetic material and is responsible for the transfer of genetic information from parents to offspring.

In 1928 Griffith conducted experiments using bacteria that causing pneumonia in mice. He used two types of bacteria; pathogenic and non-pathogenic bacteria. He observed that the non-pathogenic bacteria have absorbed genetic material (DNA) from the pathogenic bacteria. As a result they have been transformed (changed) to pathogenic form.
Later on **Avery, Mcleod and McCarty** provided experimental evidence to prove that the virulence of *Pneumococcus*, which is due to its outer surface, can be transmitted through DNA to bacteria that have lost their virulence.

Hershey and Chase who studied the life history of bacteriophages provided further conclusive evidence. Bacteriophages consist of DNA enclosed in a protein coat. The bacteriophage injects its DNA into bacterium and leaves protein coat outside. Under the instructions of the viral DNA new complete viruses (DNA and proteins) are made inside the host bacterium. This is a proof that DNA is the genetic (hereditary) material.

DNA is the data bank of living organisms. DNA molecules contain in them the master plan of all characters of every living organism. Human DNA holds all the information about the human body. All the data, such as the colour of hairs, skin or eyes, the height of body, the size, appearance and morphology of nose, fingers, ears, eyes etc. the way one looks like, inner organs, is stored in DNA. This data can be encoded using four different types of bases (adenine, thymine, guanine and cytosine).

2.6.4 Genetic Code

All genetic information is encoded in the DNA molecule in the form of gene. A gene is a unit of heredity in a living organism. All living things depend on genes, as they specify all proteins and functional RNA chains. These information are transferred to the next generation through DNA. Nucleotides are arranged in a specific way in a polynucleotide chain of DNA. A code is a sequence of three nitrogenous bases (triplet) along one sugar-phosphate strand of DNA molecule. A code specifies the way in which an amino acid is to be bonded in polypeptide chain of protein molecule.

First position (5'end)	U		C		A		G		Third position (3'end)
U	UUU	Phe	UCU	Ser	UAU	Tyr	UGU	Cys	U
	UUC	Phe	UCC	Ser	UAC	Tyr	UGC	Cys	C
	UUA	Leu	UCA	Ser	UAA	Stop	UGA	Stop	A
	UUG	Leu	UCG	Ser	UAG	Stop	UGG	Trp	G
C	CUU	Leu	CCU	Pro	CAU	His	CGU	Arg	U
	CUC	Leu	CCC	Pro	CAC	His	CGC	Arg	C
	CUA	Leu	CCA	Pro	CAA	Gln	CGA	Arg	A
	CUG	Leu	CCG	Pro	CAG	Gln	CGG	Arg	G
A	AUU	Ile	ACU	Thr	AAU	Asn	AGU	Ser	U
	AUC	Ile	ACC	Thr	AAC	Asn	AGC	Ser	C
	AUA	Ile	ACA	Thr	AAA	Lys	AGA	Arg	A
	AUG		ACG	Thr	AAG	Lys	AGG	Arg	G
G	GUU	Val	GCU	Ala	GAU	Asp	GGU	Gly	U
	GUC	Val	GCC	Ala	GAC	Asp	GGC	Gly	C
	GUA	Val	GCA	Ala	GAA	Glu	GGA	Gly	A
	GUG	Val	GCG	Ala	GAG	Glu	GGG	Gly	G

Amino acids names

- Ala = alanine
- Arg = arginine
- Asn = asparagine
- Asp = aspartate
- Cys = cysteine
- Gln = glutamine
- Glu = glutamate
- Gly = glycine
- His = histidine
- Ile = Isoleucine
- Leu = leucine
- Lys = lysine
- Met = methionine
- Phe = phenylalanine
- Pro = proline
- Ser = serine
- Thr = threonine
- Trp = tryptophan
- Tyr = tyrosine
- Val = valine

Fig: 2.23 Various combination of Genetic Codes

For your information

There is a lot of information stored in the DNA. If we had to write down all the information in the DNA, it would make 900 volumes, each of 500 pages. All this knowledge has been fitted into a tiny molecule that we cannot see with our naked eye. Who has fitted all this information in DNA. Certainly this is the work of **supreme intelligence, He is Allah with His supreme intelligence,** limitless knowledge and eternal power, Who created the universe.

There are four nitrogenous bases involved in the formation of many codes; adenine, guanine, thymine and cytosine. These four nitrogenous bases make sufficient codes for the 20 different amino acids which synthesize a large number of different protein molecules.

2.6.5 RNA as a carrier of genetic information

Three types of RNA molecules, mentioned earlier, are involved in the transfer of genetic information from DNA to synthesize proteins.This transfer of genetic information takes place in two steps:

1. Transcription

This is the transfer of genetic code from DNA molecule to RNA molecule.

2. Translation

This is the transfer of the genetic code from a mRNA to a sequence of amino acids in a polypeptide.

2.7 Conjugated Molecules

A conjugated molecule is defined as a molecule that is formed by the combination of two different molecules belonging to different categories. For example when a carbohydrate molecule combines with protein, a conjugated molecule called glycoprotein is formed. Other examples are nucleoproteins, glycolipids and lipoproteins.

1. Lipoproteins

Lipoprotein are formed by the combination of lipids and proteins. Lipoproteins are the basic structural framework of plasma membrane and all other types of membranes in the cell.

2. Nucleoproteins

Nucleoproteins are formed by the combination of nucleic acids with proteins. A eukaryotic chromosome is basically a nucleoprotein that is formed by the DNA and protein. These are slightly acidic and soluble in water.

3. Glycolipids

Glycolipids are formed by the combination of carbohydrates and lipids. Glycolipids are important component of brain and plasma membrane.

4. Glycoproteins

Glycoproteins are formed by the combination of carbohydrates and proteins. Glycoproteins are integral component of the plasma membrane. They are also present in egg albumin.

KEY POINTS

- Biochemistry is the branch of biology that deals with biochemical basis of life.
- In higher plants inorganic compounds are obtained from the environment and are used to make different organic compounds.
- Water is one of the best solvents, regulate temperature of the body and has high absorbing capacity to absorb different materials.
- Condensation is a process in which large organic molecules are synthesized and water molecules is removed.
- Hydrolysis is a process in which large organic molecules is broken down and involves the addition of water molecules.
- Carbon is present in all organic compounds with a covalent bonding capacity of four.
- Carbohydrates are generally the hydrated carbons which are composed of carbon ,hydrogen and oxygen.
- Carbohydrates are classified into monosaccharides, oligosaccharides and polysaccharides.
- Starch is a common storage product in plants and glycogen in animals.
- Cellulose is a common polysaccharides found in plants.
- Carbohydrates provide energy, a building material of different body structure and are storage molecules.
- Proteins contain carbon, hydrogen, oxygen and nitrogen as four essential elements.
- Proteins are made up of amino acids.
- The amino acids bond together by peptide bonds which produce polypeptides chains.
- Protein molecules may be fibrous e.g. keratins or globular .e.g. haemoglobin.
- Globular proteins may be primary ,secondary, tertiary and quaternary depending on their different levels of structural organization.
- Lipids are mainly composed of carbon, hydrogen and oxygen and some other elements particularly phosphorous and nitrogen and include animal fats, vegetables oils, waxes, steroids etc.

KEY POINTS

- Vegetable oils and animals fat are called triglyecrides.
- Triglycerides are with three fatty acid chains bonded to one molecules of glycerol.
- Fatty acid may be saturated or unsaturated.
- Lipids are important as storage molecules ,building material, insulators and help in the fat digestion and speeding up of vital activities.
- The two nucleic acids are Deoxyribonucleic acid (DNA) and ribonucleic acids (RNA).
- DNA has four nitrogenous bases namely ,adenine, guanine, cytosine and thymine. RNA has the nitrogenous base uracil instead of thymine.
- RNA molecule are of three types messenger RNA (m RNA) ,ribosomal (r RNA) and transfer RNA (t RNA).
- Mononucleotides may have single phosphate group .e . g. Adenosine (AMP), two phosphate groups .e .g . Adenosine diphosphate (ADP) and three phosphate group e.g. Adenosine triphosphate (ATP).
- When more than two nucleotides join together they form polynucleotides e.g. DNA and RNA.
- Example of conjugate molecules are glycoproteins, nucleoproteins, glycolipids and lipoproteins.

EXERCISE

A. Choose the correct answers for the following questions.

1. Which of the following is a disaccharide?
   a. Glucose
   b. Lactose
   c. Fructose
   d. Galactose

2. Which of the following has the greatest number of glycosidic bonds?
   a. Glucose
   b. Sucrose
   c. Cellulose
   d. Maltose

3. The main component of cellular membrane is:
   a. nucleic acid
   b. cellulose
   c. carbohydrates
   d. protein

4. The kinds of amino acids which are involved in the synthesis of proteins are :
   a. 20
   b. 30
   c. 40
   d. 50

5. Amino acids mainly differ from each other by the difference in their:
   a. R –group
   b. carboxyl group
   c. amino group
   d. alpha group

6. Keratin is a type of protein found in:
   a. silk fiber
   b. nails
   c. blood cells
   d. muscle cells

7. DNA is more or less present in all of the following EXCEPT:
   a. nucleus
   b. chromosomes
   c. ribosome
   d. mitochondrion

8. In saturated fatty acids more hydrogen are not accommodated because of:
   a. Presence of single bonds between carbon atoms
   b. Presence of double bonds between carbon atoms
   c. Presence of triple bonds between carbon atoms
   d. Absence of bond between carbon atoms

EXERCISE

9. Lipid molecules have the capacity to store double amount of energy as compared to same amount of carbohydrate because of high number of:

   a. C-C bonds b. C-H bonds
   c. C-N bonds d. C-O bonds

10. The "tails" of the hydrocarbons in the phospholipids molecules orient away from water. Which of the following describes the tail's movement away from water?

   a. Polar b. Adhesive
   c. Hydrophilic d. Hydrophobic

11. Lactose is a disaccharide formed by the formation of a glycosidic bond between glucose and ________.

   a. glyucose b. galactose
   c. Sucrose d. fructose

12. Ester linkage is a bond which involves a chemical reaction between:

   a. H_3PO_4 and COH b. H_3PO_4 and CH
   c. H_3PO_4 and COOH d. H_3PO_4 and OH

13. How many nitrogenous bases are involved in the formation genetic codes?

   a. 2 b. 3
   c. 4 d 5

B. Write short answers to the following questions.

1. Define the following:
   (a) condensation
   (b) hydrolysis
2. What are different kinds of carbohydrates? Give two example of each.
3. Compare the isomers and stereoisomers of glucose.
4. Give the chemical nature of the glycosidic bond.
5. How dehydration-synthesis and hydrolysis reactions are used for the making and breaking of macromolecule polymers.
6. Outline the synthesis and breakage of peptide linkages.
7. Evaluate the role of steroids in human body.
8. Illustrate the formation of phosphodiester bond.
9. List some examples of structural proteins.

C. Write detailed answers to the following questions.

1. Explain how the properties of water make it important for life?
2. Describe the properties and roles of disaccharides.
3. Classify proteins. List examples and roles of structural and functional proteins.
4. Describe the properties and roles of acylglycerol, terpenes and phospholipids.
5. Define conjugated molecule and describe the roles of common conjugated molecules.
6. Explain the double helical structure of DNA as proposed by the Watson and Crick.

Projects:

- Make a model exhibiting the hydrogen bonding.
- Make a simple model of ring forms of alpha and beta glucose.
- Create a 3-Dimensional model of Watson - Crick Model of DNA.

Chapter

3

Enzymes

At the end of this chapter the students will be able to:

- Describe the structure of enzyme.
- Explain the role and component parts of the active site of an enzyme.
- Differentiate among the three types of co-factors i.e. in organic ions, prosthetic group and co-enzymes, by giving examples.
- Explain the mechanism of enzyme action through Induced Fit Model, comparing it with Lock and Key Model.
- Explain how an enzyme catalyzes specific reactions.
- Define energy of activation and explain through graph how an enzyme speeds up a reaction by lowering the energy of activation.
- Describe the effect of temperature on the rate of enzyme action
- Compare the optimum temperatures of enzymes of human and thermophilic bacteria.
- Describe the range of pH at which human enzymes function
- Compare the optimum pH of different enzymes like trypsin, pepsin, pepane etc.
- Describe how the concentration of enzyme affects the rate of enzyme action.
- Explain the effect of substrate concentration on the rate of enzyme action.
- Describe enzymatic inhibition, its types and its significance.
- Name the molecules which act as inhibitors.
- Categorize inhibitors into competitive and non-competitive inhibitors.
- Explain feedback inhibition.
- Classify enzymes on the basis of the reactions catalyzed (oxido-reductases, transferases, hydrolases, hydrolyases, isomerases, and ligases).
- Classify enzymes on the basis of the substrates they use (lipases, diastase, amylase, proteases etc).

Introduction

Recall from your pervious classes that enzymes are biological catalyst which increase the rate of chemical reaction in living cells without being used in the process. Nearly every chemical process that takes place in living things is facilitated by an enzyme. The sum of all the chemical reactions that a cell or larger living thing carries out is its metabolism. Many activities in living things are controlled by metabolic pathways in which a series of interrelated steps are involved each one of them facilitated by an enzyme.

3.1 Enzyme Structure

Enzymes are proteins, and their function is determined by their complex structure. The reaction takes place in a small part of the enzyme called the active site, while the rest of the protein acts as "framework". The amino acids around the active site attach to the substrate molecule and hold it in position while the reaction takes place. This makes the enzyme specific for one reaction only, as other molecules would not fit into the active site.

3.2 Mode of Enzyme Action

Following two hypotheses explains mode of enzyme action

3.2.1 Lock and Key Hypothesis

Fischer in 1890 suggested that each enzyme had a particular shape into which the substrate fit exactly. This was known as the lock and key hypothesis. According to this hypothesis the substrate is imagined like a lock while the enzyme is imagined like a key. As one specific key can open only a specific lock, similarly a specific enzyme can break up only one specific substrate. The active site is regarded as rigid structure that does not modify or change during the reaction process. However later studies did not support this hypothesis in all type of reactions and therefore the hypothesis was modified into Induced fit hypothesis.

3.2.2 Induced-Fit Hypothesis

The attraction of the substrate and enzyme form an enzyme-substrate complex. It was originally referred to as the Lock and Key Enzyme Theory. The current theory suggests that the enzyme molecules are in an inactive form. To become active they must undergo a slight change in structure to more specifically accommodate the substrate(s). It is said to be "induced to fit" the substrate.

Think of way your hand changes shape slightly when you shake a person's hand. There are three ways of thinking about enzyme catalysis. They all describe the same process, though in different ways, and you should know about each of them.

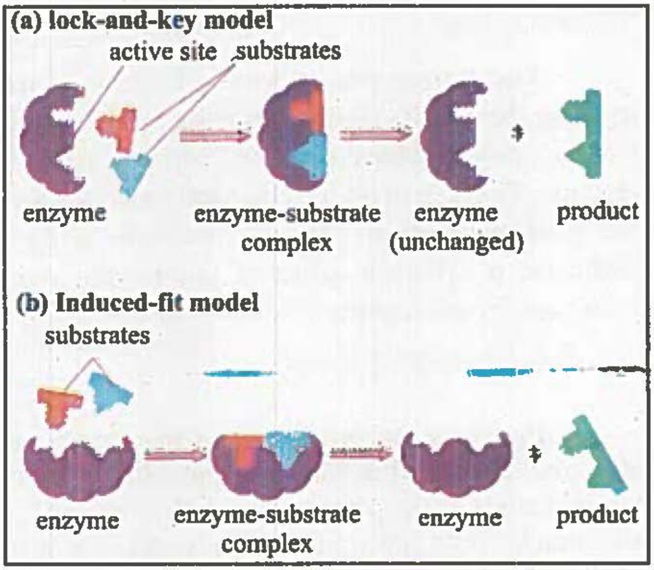


Fig: 3.1 Mechanism of Enzyme Action

A. Reaction Mechanism

In any chemical reaction, a substrate (S) is converted into a product (P):

$$S \sim P$$

There may be more than one substrate and more than one product, but that doesn't matter here. In an enzyme-catalyzed reaction, the substrate first binds to the active site of the enzyme to form an enzyme-substrate (ES) complex, then the substrate is converted into product while attached to the enzyme, and finally the product is released. This mechanism can be shown as in the Fig 3.2. The enzyme is then free to start again.

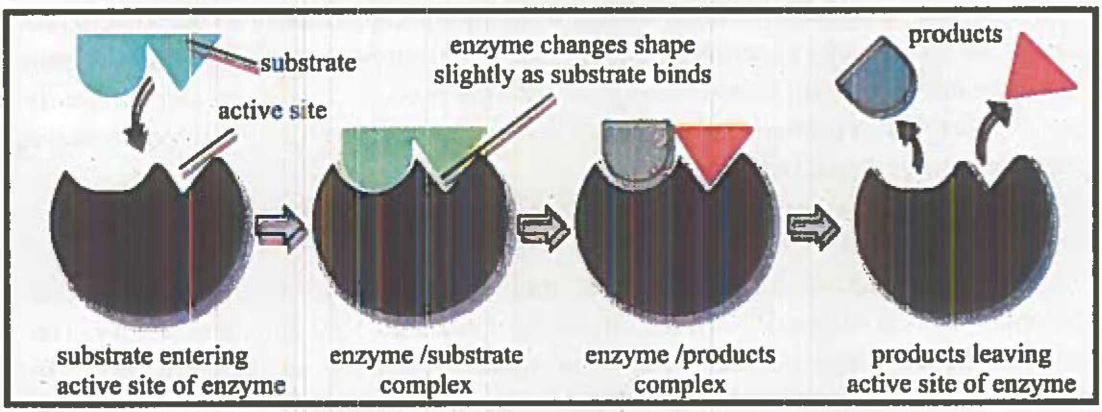


Fig: 3.2 Sequence of events in enzyme controlled reaction

B. Molecule Geometry

The substrate molecule fits into the active site of the enzyme molecule like a key fitting into a lock. Once there, the enzyme changes shape slightly, distorting the molecule in the active site, and making it more likely to change into the product. For example if a bond in the substrate is to be broken, that bond might be stretched by the enzyme, making it more likely to break. Alternatively the enzyme can make the local conditions inside the active site quite different from those outside (such as pH, water concentration, charge), so that the reaction is more likely to happen.

C. Energy Changes

The way enzymes work can also be shown by considering the energy changes that take place during a chemical reaction. We shall consider a reaction where the product has a lower energy than the substrate, so the substrate naturally turns into product (in other words the equilibrium lies in the direction of the product). Before it can change into product, the substrate must overcome an "energy barrier" called the activation energy (E_A). The larger the activation energy, the slower the reaction will be because only a few substrate molecules will by chance have sufficient energy to overcome the activation energy barrier. Enzymes dramatically reduce the activation energy of a reaction, so that most molecules can easily get over the activation energy barrier and quickly turn into product. *For* example, for the following reaction

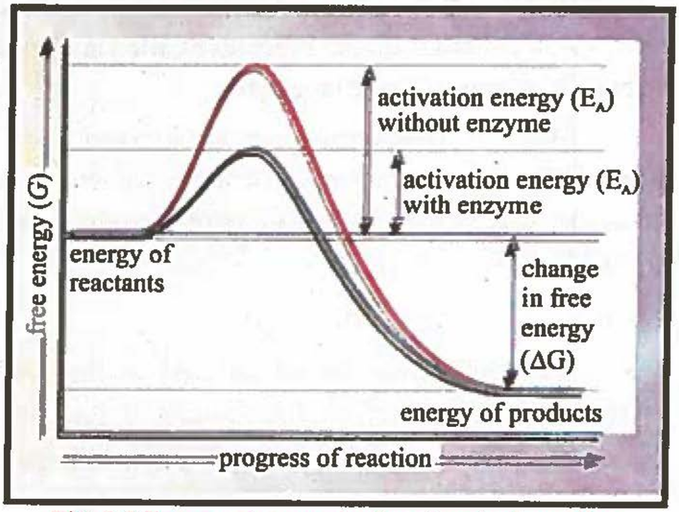


Fig: 3.3 Energy changes during chemical reaction.

$$2H_2O_2 \longrightarrow 2H_2O + O_2$$

The activation energy is 86 kJ mol^{-1} with no catalyst and just 1 kJ mol^{-1} in the presence of the enzyme catalase.

The activation energy is actually the energy required to form the transition state, so enzymes lower the activation energy by stabilising the transition state, and they do this by changing the conditions within the active site of the enzyme.

3.3 Cofactors

Cofactors - are atoms, groups of atoms and molecules that join with enzymes altering their shape and making them functional. One can think of these cofactors as an" on-off" switch for activating an enzyme. If the cofactor is a non-protein like a metallic ion (i.e. zinc, copper, or iron) it is referred to as a prosthetic group. Some cofactors are small organic molecules called coenzymes. Like enzymes they are not permanently altered in the reactions.

Many of these coenzymes are derived from vitamins and minerals that are essential for life. The absence of these cofactors can lead to vitamin and mineral deficiency diseases e.g lack of Vitamin B produces beriberi . Examples of coenzymes are NAD^+, FAD^+, NADP.

3.4 Enzyme nomenclature

Many enzymes but not all end in the suffix "ase". (exceptions: pepsin, trypsin). They are named for the substrate they act on or the action they perform.

The following are the six major enzyme categories.

1. Oxidoreductases

These enzymes catalyze various types of oxidation-reduction reactions. Subclasses of this group contain oxidases, oxygenases and peroxidases.

2. Transferases

These enzymes catalyze reactions that involve the transfer of groups from one molecule to another. Examples of such groups include amino, carboxyl, methyl and carbonyl. Transcarboxylases and transmethylases are examples of transferases.

3. Hydrolases

These enzymes catalyze the reactions in which the cleavage of bonds is accomplished by the addition of water. The hydro lases include the esterases, phosphatases and peptidases

Table 3.1 Enzyme Nomenclature by Substrate

Substrate	Enzyme
Lipid	Lipase
Urea	Urease
Maltose	. Maltase
Ribonucleic Acid (RNA)	RNAase
A TP	ATPase
Dextrose	Dextrase
Protein	Proteinase

4. Lyases

Lyases catalyze reactions in which groups (e.g. H_2O, CO_2 and NH_3) are removed to form a double bond or added to a double bond .Decarboxylases, deaminases and synthases are examples of Lyases.

5. Isomerases

This is a heterogeneous group of enzymes which catalyze several types of intermolecular rearrangements. Epimerases and mutases are the examples.

6. Ligases

Ligases catalyze bond formation between two substrate molecules. The energy for these reactions is always supplied by ATP hydrolysis.

3.5 Factors that Affect the Rate of Enzyme Reactions

Rate of enzyme reactions depend on the following factors.

A. Temperature

Enzymes works best at an optimum temperature. Enzymes present in mammals works best at about 40°C. Animals present in different environments are adopted to range of temperature. for example, enzymes of the arctic snow flea work at -10°C whereas in thermophilic bacteria enzymes work at a temperature of 90°C.Upto the optimum temperature the rate increases geometrically with temperature (i.e. it's a curve, not a straight line). The rate increases because the enzyme and substrate molecules both have more kinetic energy so collide more often and also because more molecules have sufficient energy to overcome the (greatly reduced) activation energy. The increase in rate with temperature can be quantified as a Q IO, which is the relative increase for a 10°C rise in temperature.

The rate is not zero at O°C, so enzymes still work in the refrigerator (and food still goes off), but they work slowly. Enzymes can even work in ice, though the rate is extremely slow due to the very slow diffusion of enzyme and substrate molecules through the ice lattice.

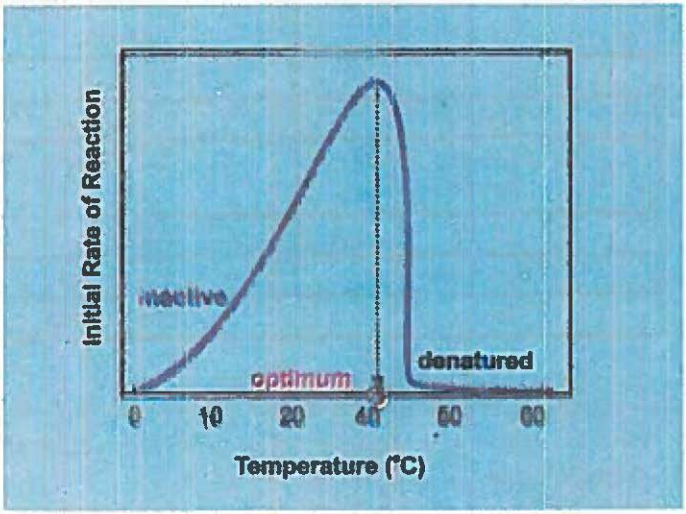


Fig: 3.4 Influence of temperature on the rate of enzyme-catalyzed reactions.

B. pH

Enzymes have an optimum pH at which they work fastest. For most enzymes this is about pH 7-8 (physiological pH of most cells), but a few enzymes can work at extreme pH, such as protease enzymes in animal stomachs, which have an optimum pH 1. The pH affects the charge of the amino acids at the active site more specifically, changes in pH ionizes amino acids forming an enzyme so the properties of the active site change and the substrate can no longer bind.

For your information

Enyzme	pH Optimum
Lipase (Pancreas)	8.0
Lipase (Stomach)	4.0-5.0
Lipase (Castor oil)	4.7
Pepsin	1.5-1.6
Trypsin	7.8-8.7
Urease	7.0
Invertase	4.5
Maltase	6.1-6.8
Amylase (Pancreas)	6.7-7.0
Amylase (malt)	4.6-5.2
Catalase	7.0

C. Enzyme concentration

As the enzyme concentration increases the rate of the reaction increases linearly, because there are more enzyme molecules available to catalyze the

reaction. At very high enzyme concentration the substrate concentration may become rate-limiting, so the rate stops increasing. Normally enzymes are present in cells in rather low concentrations.

D. Substrate concentration

The rate of an enzyme-catalyzed reaction shows a curved dependence on substrate concentration. As the substrate concentration increases, the rate increases because more substrate molecules can collide with enzyme molecules, so more reactions will take place. At higher concentrations the enzyme molecules become saturated with substrate, so there are few free enzyme molecules, so adding more substrate doesn't make much difference.

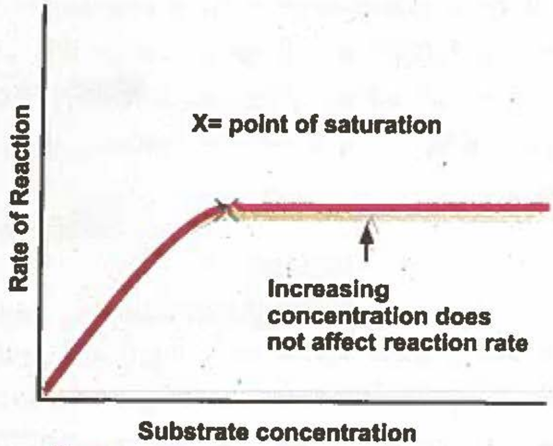


Fig: 3.5 Effect of substrate concentration on rate of reaction.

E. Inhibitors

Inhibitors inhibit the activity of enzymes, reducing the rate of their reactions. They are found naturally, but are also used artificially as drugs, pesticides and research tools. There are two kinds of inhibitors.

(a) **A competitive inhibitor molecule** has a similar structure to the normal substrate molecule, and it can fit into the active site of the enzyme. It therefore competes with the substrate for the active site, so the reaction is slower e.g the sulphonamide to an antibacterial drugs which act as competitive inhibitors.

(b) **A non-competitive inhibitor molecule** is quite different in structure from the substrate molecule and does not fit into the active site. It binds to another part of the enzyme molecule, changing the shape of the whole enzyme, including the active site, so that it can no longer bind substrate molecules. Inhibitors that bind weakly and can be removed out easily are sometimes called reversible inhibitors, while those that bind tightly and cannot be removed out are called irreversible inhibitors. Poisons like cyanide, heavy metal ions and some insecticides are all non-competitive inhibitors.

The activity of some enzymes is controlled by certain molecules binding to a specific regulatory (or allosteric) site on the enzyme, distinct from the active site. Different molecules can inhibit or activate the enzyme, allowing sophisticated control of the rate. Only a few enzymes can do this, and they are often at the start of a long biochemical pathway. They are generally activated by the substrate of the pathway and inhibited by the product of the pathway, thus only turning the pathway on when it is needed.

3.6 Feedback Inhibition

Another kind of inhibition is called feedback inhibition. In feedback inhibition, there is a second binding site on the enzyme where the inhibitor binds, so that the inhibitor is not necessarily similar in structure to the substrate. The absence or presence of the inhibitor at this second binding site activates or deactivates the enzyme, by changing the conformation of the enzyme so that the active site is made available or unavailable to the substrate. The inhibitor is usually the product of a reaction formed during the metabolic pathway.

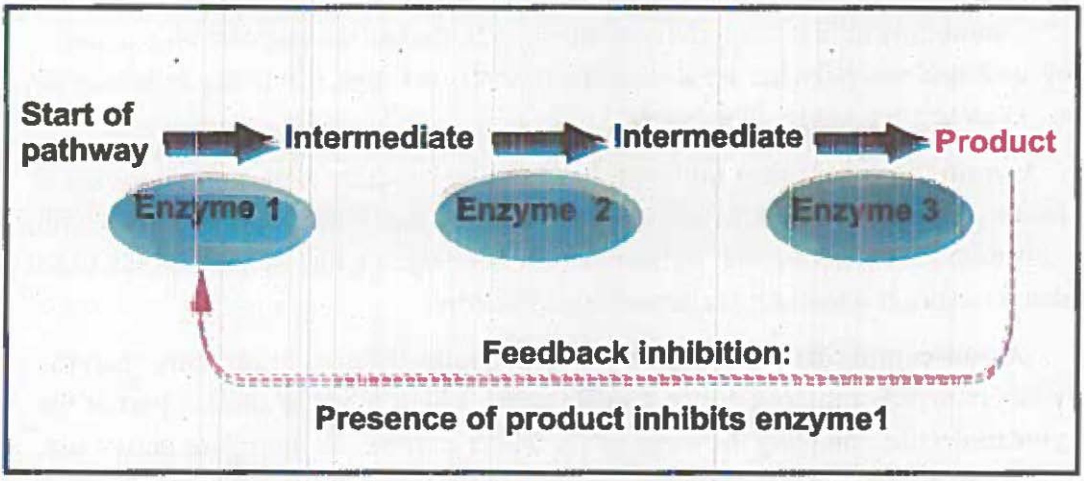


Fig: 3.6 Feedback inhibition.

KEY POINTS

- Enzymes are organic chemical substances produced by the living organisms to speed up a particular reaction, but during this process these remain unchanged.
- Enzymes are very specific in their action acting on a specific substrate.
- When an enzymes acts on a specific substrate, enzymes substrates complex is formed.
- When enzyme's shapes are disrupted it loses its characteristics biological activity.
- The non protein part or prosthetic group of an enzyme is called cofactor.
- According to lock and key model of enzyme the active site of an enzyme is a rigid structure.
- Modification to the lock and key model suggests that since enzymes are rather flexible structures, the active site is continually reshaped by interactions with the substrate as the substrate interacts with the enzyme.
- An inhibitor is a chemical substance which can block the active site of an enzyme temporarily or permanently by stopping the activity of the enzyme.
- The factors that affect the rate of enzyme action are: enzymes concentration, substrate concentration, temperature, pH of the medium.
- A cellular control mechanism in which an enzyme that catalyzes the production of a particular substance in the cell is inhibited when that substance has accumulated to a certain level, thereby balancing the amount provided with the amount needed.

EXERCISE

A. Choose the correct answers in the following questions.

1. Which one enzyme catalyzes the oxidation-reduction reaction?
   a. Oxygenases b. Transmethylases
   c. Lyases d. Peptidases
2. Enzyme catalyzing rearrangement of atomic groupings without altering molecular weight or number of atoms is:
   a. ligase b. isomerase
   c. oxidoreductase d. hydrolase
3. Enzymes are polymers of:
   a. hexose sugar b. amino acids
   c. fatty acids d. inorganic molecules
4. Which one forms the raw material for coenzymes?
   a. Vitamins b. Carbohydrates
   c. Proteins d. Metals
5. What will happen to reaction if enzyme is added?
   a. Rate of reaction decreases b. Rate of reaction increase
   c. No effect on the rate of reaction d. Reaction is reversed
6. What is induced fit hypothesis?
   a. When enzyme change shape due to absence of substrate
   b. When enzyme do not change shape due to absence of substrate
   c. When enzyme change shape due to presence of substrate
   d. When enzyme do not change shape due to presence of substrate
7. Which enzyme digest` egg albumin into peptides and amino acids best in alkaline conditions?
   a. Catalase b. Lipase
   c. Pepsin d. Trypsin
8. Sometimes enzyme and substrate are held together by the kind of bonds called:
   a. Ionic b. hydrogen
   c. hydrophobic d. covalent
9. Which one of the following refers to non competitive inhibitors:
   a. Bind to the active site.
   b. Similar to the normal substrate with which energy interact
   c. Destroy the globular conformation of enzyme
   d. Bind to the binding site other than active site

EXERCISE

10. Which one of the following factors does not affect the rate of enzyme action?
    a. Enzymes concentration
    b. Substrate concentration
    c. Water concentration
    d. Temperature

11. The optimum pH value for pepsin to work is :
    a. 6.8
    b. 4.5
    c. 5.5
    d. 1.5

B. Write short answers to the following questions.

1. What is a cofactor? Give examples.
2. What are metal activators? Give three examples.
3. Differentiate the key difference between the Lock and Key Model and Induced Fit Hypothesis/model?
4. How pH of a cell affects the enzyme activity?

C. Write detailed answers to the following questions.

1. Describe the characteristics of enzymes.
2. Explain the process of enzyme inhibition. Make a list of some common enzymes inhibitors.
3. Write briefly the mode of action of an enzyme.
4. How do the enzyme and substrate concentrations affect the rate of enzyme action?

Projects

- Search and make a list of enzymes which are used for diagnostic purposes in your local diagnostic laboratory.
- List down some common venoms which can act as enzyme inhibitors.
- Enzymes are three-dimensional, create a unique three-dimensional enzyme model using low cost no cost material. Identify your model in terms of the name of enzyme and substrate, active site, enzyme substrate complex, products.

4 Bioenergetics

At the end of this chapter students will be able to:

- Explain the role of light in photosynthesis.
- Identify the two general kinds of photosynthetic pigments (carotenoids and chlorophylls).
- Describe the roles of photosynthetic pigments in the absorption and conversion of light energy.
- Differentiate between the absorption spectra of chlorophyll 'a' and 'b'.
- Describe the arrangement of photosynthetic pigments in the form of photosystem-I and II.
- State the role of CO_2 as one of the raw materials of photosynthesis.
- Explain, narrating the experimental work done, the role of water in photosynthesis.
- Describe the events of non-cyclic photophosphorylation and outline the cyclic photophosphorylation.
- Explain the Calvin cycle (the regeneration of RuBP should be understood in outline only).
- Explain the process of anaerobic respiration in terms of glycolysis and conversion of pyruvate into lactic acid or ethanol.
- Outline (naming the reactants and products of each step of) the events of glycolysis.
- Illustrate the conversion of pyruvate to acetyl-CoA.
- Outline (naming the reactants and products of each step of) the steps of Krebs cycle.
- Explain the passage of electron through electron transport chain.
- Describe chemiosmosis and relate it with electron transport chain.
- Explain the substrate-level phosphorylation during which exergonic reactions are coupled with the synthesis of ATP.
- Justify the importance of PGAL in photosynthesis and respiration.
- Outline the cellular respiration of proteins and fats and correlate these with that of glucose.
- Define photorespiration and outline the events occurring through it.
- Rationalize how the disadvantageous process of photorespiration evolved.
- Explain the effect of temperature on the oxidative activity of RuBP carboxylase.
- Outline the process of C4 photosynthesis as an adaptation evolved in some plants to deal with the problem of photorespiration.

Introduction

This chapter deals with the most fundamental metabolic processes i.e. photosynthesis and respiration. Bioenergetics is the study of energy transformation in biological systems. Metabolic processes are going on all the times inside the bodies of living organisms. These processes involve chemical reactions that are concerned with making or breaking of bonds in the molecules. When chemical bonds are broken, energy is released and when bonds are formed, energy is stored. All living cells use energy for performing functions. Sunlight is the main source of energy maintaining all life forms on the earth. But no organism can make use direct energy of sunlight as source of energy for metabolism. All organisms use chemical energy stored in food molecules such as carbohydrates, fats etc. Photosynthesis is carried out by green plants which capture solar energy, transform it into chemical energy and is stored in organic compounds.

4.1. Photosynthesis

Photosynthesis is the process in which green plants synthesize organic food from carbon dioxide and water using energy of sunlight. CO_2 and water are used as raw materials in the process for synthesis of organic food molecules. Chlorophylls and other photosynthetic pigments capture energy of sunlight and convert it into chemical energy.

Photosynthesis acts as energy capturing and storing process. Energy of sunlight is used in the fixation of carbon dioxide to a carbohydrate. This serves as food not only for plants but for the entire life on the planet earth. Therefore all living organisms, directly or indirectly depends on photosynthesis. Autotrophic organisms which are the green plants are able to carry out photosynthesis. Heterotrophic organisms cannot carry out photosynthesis and are unable to use direct energy of sunlight. They, therefore, are dependent for their energy requirement on green plants.

Point To Ponder

Imagine if the process of photosynthesis stops what would be the state of life condition on earth?

Overall reaction of photosynthesis is:

$$6CO_2 + 12H_2O \xrightarrow[\text{(chlorophyll)}]{\text{(Light)}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

Photosynthetic Reactants and Products:

The water and carbon dioxide are the reactants in photosynthesis while glucose, oxygen and water are the products.

4.1.1. The Role of Sunlight in Photosynthesis

Sun is the main source of energy for all living organisms. Light is a kind of energy tqchat travels in the form of electromagnetic waves of different wavelengths. It also acts as beam of particles of different frequencies called photons. There is a wide range of waves for synthesis of organic food molecules (wavelengths occurring between gamma rays and radio rays). Energy content of photons is inversely proportional to the wavelengths. Short wavelengths are more energetic i.e. have high energy content than long wave lengths. A portion of the solar radiation is called visible spectrum.

Our eyes are sensitive to only a small portion of this solar radiation i.e. visible light that ranges from about 390 nm to 760 nm in wavelength. Photosynthetic pigments absorb and utilize a portion of the visible spectrum. Wavelengths shorter than the visible light i.e. ultraviolet radiation are more energetic and are dangerous to the cells because they can break organic molecules. Wavelengths longer than visible light i.e. infrared have low energy content that cannot affect photosynthetic process. Wavelengths of the visible spectrum have the right amount of energy absorbed by photosynthetic pigments for photosynthesis.

About forty percent of the total of sunlight that enters our atmosphere reaches the earth surface. Most of this radiation is within the visible light range. Dangerous higher energy wavelengths are screened out by the ozone layer and upper layers of the atmosphere. Lower energy wavelengths are mostly absorbed or reflected by water vapours and other gases and are scattered in the atmosphere.

Of the total sunlight that strikes the green plants only about a fractionis used in the photosynthesis. This small portion of sunlight sustains all forms of life on earth. There are two types of photosynthetic pigments i.e. chlorophylls and carotenoids. Chlorophylls absorb mostly violet-blue wavelengths (390-460nm) and red wavelengths (630-700nm).

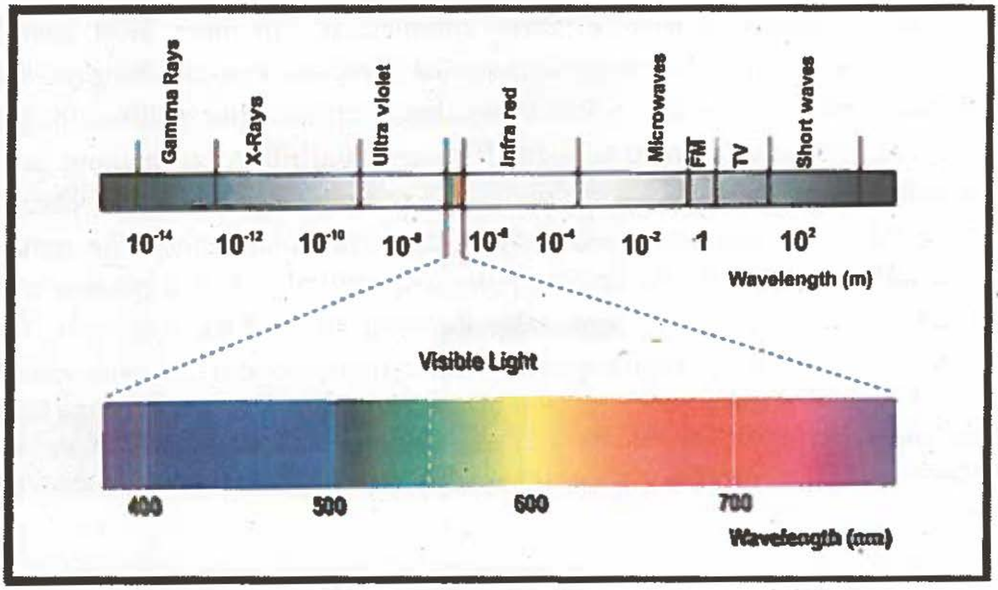


Fig: 4.1 Electromagnetic radiation that has a wavelength between 380nm and 780nm is visible to the human eye and is commonly referred to as light.

For Your Information

Quran says "And made the moon a light in their midst, and made the sun as a (Glorious) Lamp?

Sura Noor Aayah:16.

"And placed (therein) a blazing lamp (sun).

Sura An naba. Aayah: 13

"Blessed is He Who made constellations in the skies, and placed therein a Lamp and a Moon giving light;

Sura Al-fur'qan Aayah: 61

Green wavelengths are mostly reflected therefore chlorophyll appears green. The carotenoids which are called accessory pigments absorb light in the visible spectrum ranging between 500nm and 600 nm in wavelengths.

4.1.2. Photosynthetic Pigments

Photosynthetic pigments absorb different wavelengths of solar radiation. There are two types of photosynthetic pigments involved in photosynthesis. These are chlorophylls and carotenoids. In eukaryotes photosynthetic pigments are located in the chloroplasts.

A chloroplast consists of three components; An outer most covering (envelop), **grana** (singular granum) and stroma. The outer most covering (envelop) of the chloroplast is formed by a double membrane structure that encloses the grana and stroma. A granum consists of many flattened fluid-filled membranous sacs or discs called thylakoids which form stacks and resemble a pile of coins. There are many grana which are interconnected by lamellae called intergrana. The grana are visible under the light microscope as grains. Chlorophyll and other photosynthetic pigments (carotenoids) are present within the membranes of the thylakoids. These membranes are the sites of light trapping reaction (light reaction) of photosynthesis.

The double membranes envelop of the chloroplast surrounds a large central space called **stroma.** The stroma contains enzyme rich gel-like solution called matrix where light independent reaction (dark reaction) of photosynthesis takes place.

a. Chlorophylls

Chlorophyll is a complex organic compound. It absorbs mainly blue and red portion of sunlight. The green portion is mainly reflected therefore chlorophyll appears green. There are many types of chlorophyll i.e. Chlorophyll a, b, c, d, e and bacteriochlorophyll

Do You Know?

Photosynthetic prokaryotes lack chloroplasts but they do have unstacked photosynthetic membrances, which work like thylakoid membrane. Chlorophyll is attached to the thylakoid membrane

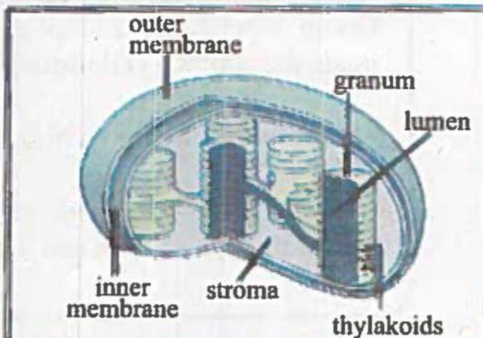


Fig:4.2Chloroplast

Chlorophyll "a" is the most abundant and most important photosynthetic pigment. It is found in all green plants except bacteria. It exists in several forms depending on its arrangement in the membrane. Chlorophyll "b" is found in all higher plants and green algae. Chlorophyll "c", d and "e" are found in various groups of algae. Bacterio-chlorophyll is found in bacteria.

Chlorophyll molecule is composed of two parts, i.e. head and tail. The head contains a central magnesium atom to which are attached four N-rings called Pyrrole rings. The four rings (tetra Pyrrole ring) are collectively called porphyrin. The head is hydrophilic and lies on the surface of the thylakoid membrane. Long hydrocarbon chain called phytol side chain (tail) is attached to one of the Pyrrole rings. It is hydrophobic. It lies embedded in the thylakoid membrane.

Chlorophyll "a" and "b" differ from each other in only one of the functional groups bonded to the **porphyrin**. Chlorophyll "a" has methyl group ($-CH_3$) while Chlorophyll "b" has carbonyl group ($-CHO$). The empirical formulae of chlorophyll "a" and "b" are
Chlorophyll "a" ($C_{55}H_{72}O_5N_4Mg$)
Chlorophyll "b" ($C_{55}H_{70}O_6N_4Mg$)

b. Carotenoids

They include carotenes and xanthophylls. They are yellow, orange, red or brown pigments. Carotenoids play two important roles in plants. They absorb light and transfer light energy to chlorophyll "a". Therefore, they are called accessory pigments. Carotenoids protect chlorophyll from intense light and from oxidation by oxygen produced in photosynthesis.

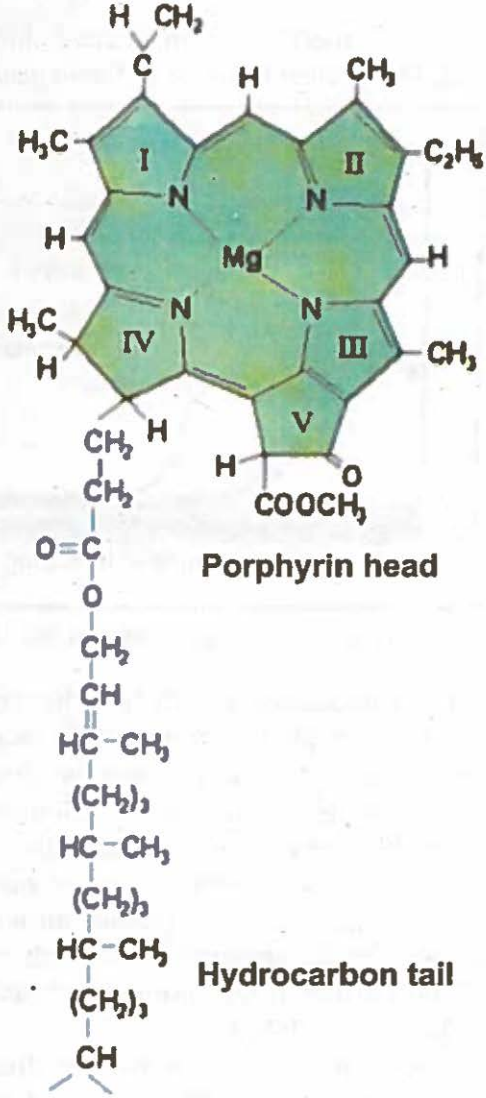


Fig: 4.3 Chemical structure of Chlorophyll

4.1.3. Absorption Spectra of Chlorophylls and Carotenoids

Absorption spectrum is the amount of light absorbed at different wavelengths from the visible spectrum of light. Photosynthetic pigments absorb light only in the visible part of light spectrum. The most important pigments in photosynthesis are chlorophyll "a" and chlorophyll "b". They chiefly absorb light in violet blue (390 nm – 460 nm) and red parts (630nm - 700 nm) of the spectrum.

The absorption spectra of both of these chlorophylls are somewhat different from each other. This is clear from the different peaks as shown inthe following fig 4.4.

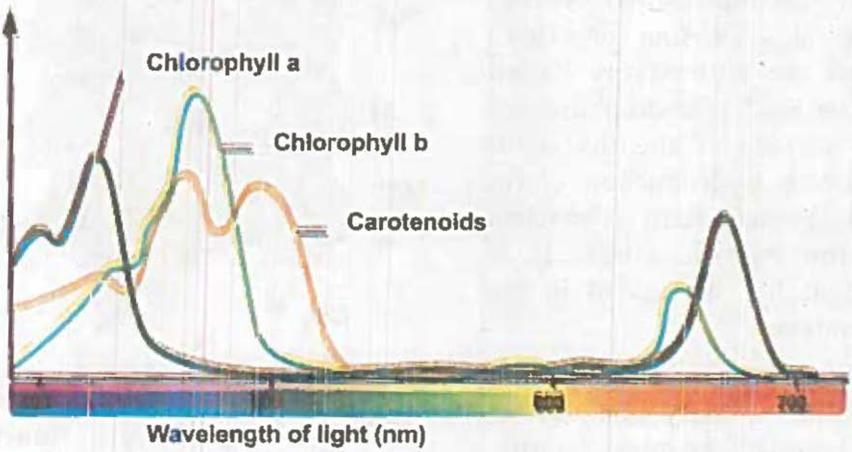


Fig: 4.4 Absorption Spectra of Chlorophylls and Carotenoids

The carotenoids absorb light between 430-470 nm of light spectrum and' transfer it to chlorophyll 'a' molecule. To measure the absorption of a pigment, a pure solution of the extracted pigment is obtained. It is then exposed to different wavelengths of light inside spectrophotometer. It is an instrument that measures the amount of light that passes through the solution. The amount of light can be calculated from the amount projected on the solution and the amount of light received at the other end after passing through the spectrophotometer. This gives the measurement of the absorpticn spectrum of a particular pigment. Chlorophyll "a" and "b" show different absorption spectra as shown above.

4.1.4 Action Spectrum

Action spectrum is a measure of effectiveness of light of various wavelengths in driving photosynthesis. Whole amount of energy absorbed by the pigments is not stored in organic compounds. Some of it is released as heat and the rest is stored in organic compounds as chemical energy.

Action spectrum of a particular pigment can be calculated by measuring the rate of photosynthesis at each type of wavelength of light. As photosynthesis produces oxygen; the rate of production of oxygen can be used as a measure of the rate of photosynthesis. This gives an action spectrum of photosynthetic pigments for different wavelengths. Red and blue turn out to be the most effective wavelengths in photosynthesis. The action spectrum is somewhat different from absorption spectrum of chlorophyll.

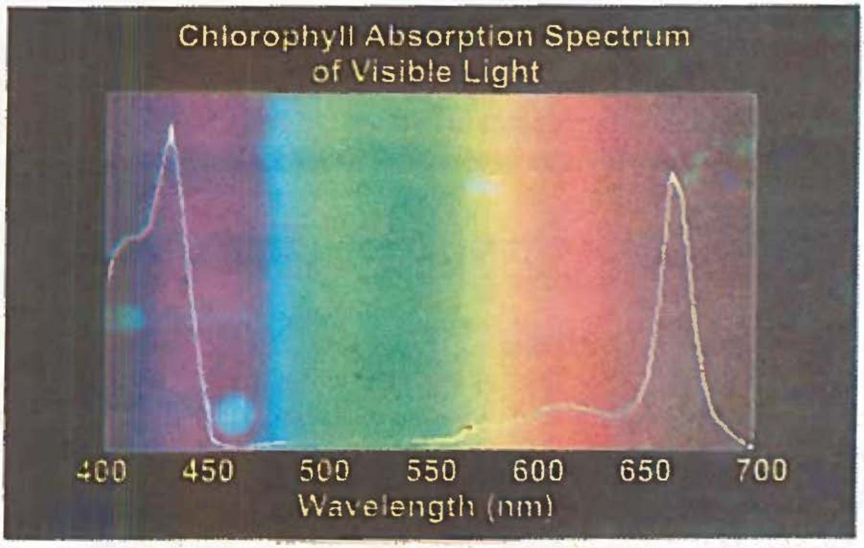


Fig: 4.5 Action Spectrum of Chlorophyll

4.1.5 Role of CO_2 as one of the raw materials of photosynthesis

The carbon of CO_2 is fixed in organic compounds in photosynthesis. Carbon is most important component of organic compounds. Carbon-carbon chain forms the back bone of the long hydro-carbon molecule and makes a stable and symmetric compound. Carbon makes bonds with oxygen linking the monosaccharide of carbohydrates. It makes bonds with nitrogen linking amino acids of protein molecules. Carbon dioxide is used as one of the raw material for photosynthesis. In the absence of carbon dioxide the process of photosynthesis does not occur.

4.1.6 Role of water in photosynthesis

Water is one of the raw materials used in photosynthesis. Water molecule is broken down into hydrogen and oxygen. Hydrogen combines with carbon dioxide forming organic food molecule. Oxygen is released into the air and is the source of atmospheric oxygen.

Earlier it was thought that the oxygen released in the process of photosynthesis comes from CO_2. In 1930, **Van Neil** hypothesized that plants split water to release oxygen as a by-product. The idea of Neil was supported by Hill. In 1937 he observed that when isolated chloroplasts were given light in complete absence of CO_2 and some hydrogen acceptor was present oxygen is released. Other scientists later confirmed **Neil's** hypothesis when first use of an isotopic tracer (O^{18}) in biological research was made. Water and carbon dioxide containing heavy-oxygen isotope O^{18} were prepared in the laboratory.

Experimental green plants in one group were supplied with H_2O containing O^{18} and with CO_2 containing only common oxygen O^{16}. Plants in the second group were supplied with water containing common oxygen O^{16} but with CO_2 containing O^{18}. It was found that plants of first group produced O^{18} but the plants of second group did not.

Group I $CO_2^{16} + 2H_2O^{18} \longrightarrow CH_2O^{16} + H_2O + O_2^{18}$

Group II $CO_2^{18} + 2H_2O^{16} \longrightarrow CH_2O^{18} + H_2O + O_2^{16}$

4.2 Mechanism of Photosynthesis

The Mechanism of photosynthesis consists of two distinct steps; one that requires light is called **light reaction** and the other that does not require light called **dark reaction**.

4.2.1 Light Reaction (Light dependent reaction)

Light reaction takes place in the granum of chloroplast. It is initiated when photosynthetic pigments capture light energy. Photosynthetic pigments are organized into clusters called photosystems. There are two photosystems i.e. photosystem I (PS I) and photosystem II (PS II). Each photosystem consists of several hundred pigment molecules including chlorophyll a, chlorophyll b, carotenoids and electron acceptors. There are two parts of each photosystems i.e. antenna complex and reaction center. The antenna complex has many molecules of chlorophyll b and carotenoids, all absorb energy and transfer it to the reaction center. Reaction center has one or more molecules of chlorophyll a molecules along with primary electron acceptor and electron carriers.

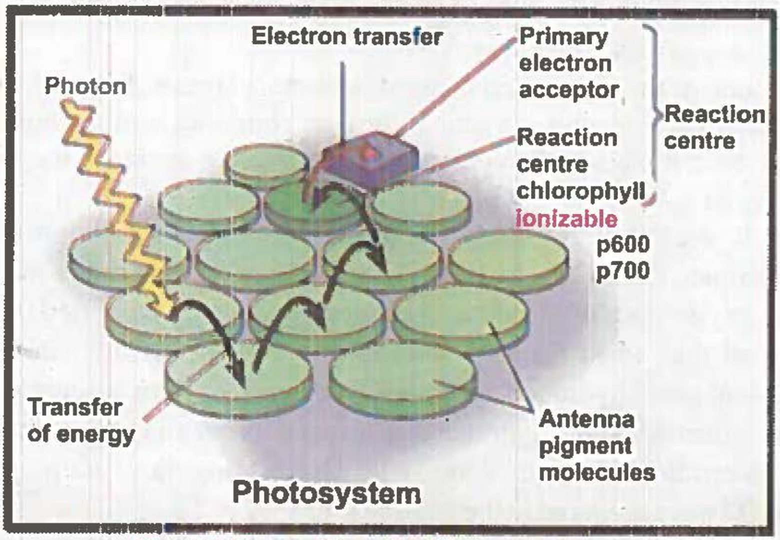


Fig: 4.6 Composition of a Photosystem

Photosystem I absorbs light of 700 nm and is called P700 whereas photosystem II absorbs light of 680 nm and is called P680. The primary electron accepter traps the electrons from the reaction center and then passes them on to the series of electron carriers. There are two possible pathways of the electrons in the light reaction of photosynthesis. They are called non-cyclic electron transport and cyclic electron transport

a. Non Cyclic Electron Transport of Light Reaction

- This reaction starts when sunlight strikes the photosystem II (P 680). Energy is absorbed by the chlorophyll molecules which loses its two electrons and becomes positively charged with a deficit of two electrons.
- The lost high energy electrons are captured by an electron acceptor called Plastoquinone (PQ).
- From plastoquinone the electrons pass along a series of electron transport chain which includes cytochrome 'b', cytochrome 'f' and plastocyanin molecules.
- Each molecule in the electron transport chain is alternately reduced when it gains electron and is oxidized when it losses electrons.
- When electrons are passed through electron transport chain, they lose energy. This energy is used in making ATP from ADP and inorganic phosphate using energy from sunlight in a process called as **photophosphorylation.**
- The electrons from plastocyanin are received by another photosystem called photosystem I (P700).
- At the same time light falls on photosystem I and activates its two electrons which are received by Ferredoxin reducing substance (FRS); electron accepter of PS I. From FRS electrons are passed to oxidized NADP (Nicotinamide adenine dinucleotide phosphate). The reduced NADP receives hydrogen from water and is converted into $NADPH_2$
- When photosystem II absorbs light, water molecule splits (photolysis) into OH^- and H^+. The OH^- ions react to form some water again and release oxygen and electrons.

$$4H_2O \longrightarrow 4H^+ + 4(OH^-)$$
$$4(OH^-) \longrightarrow 2H_2O + O_2$$

- Electrons from water molecules are accepted by positively charged chlorophyll molecule of Photosystem II, filling the gap produced by the two energized electrons. The electron deficiency of photosystem I has been filled by electrons coming from photosystem II.

This transport of electrons is called **Non cyclic electron transport** because electrons don not move in a cycle. The ATP synthesis during this non-cyclic electron flow is called **Non-cyclic Photophosphorylation.**

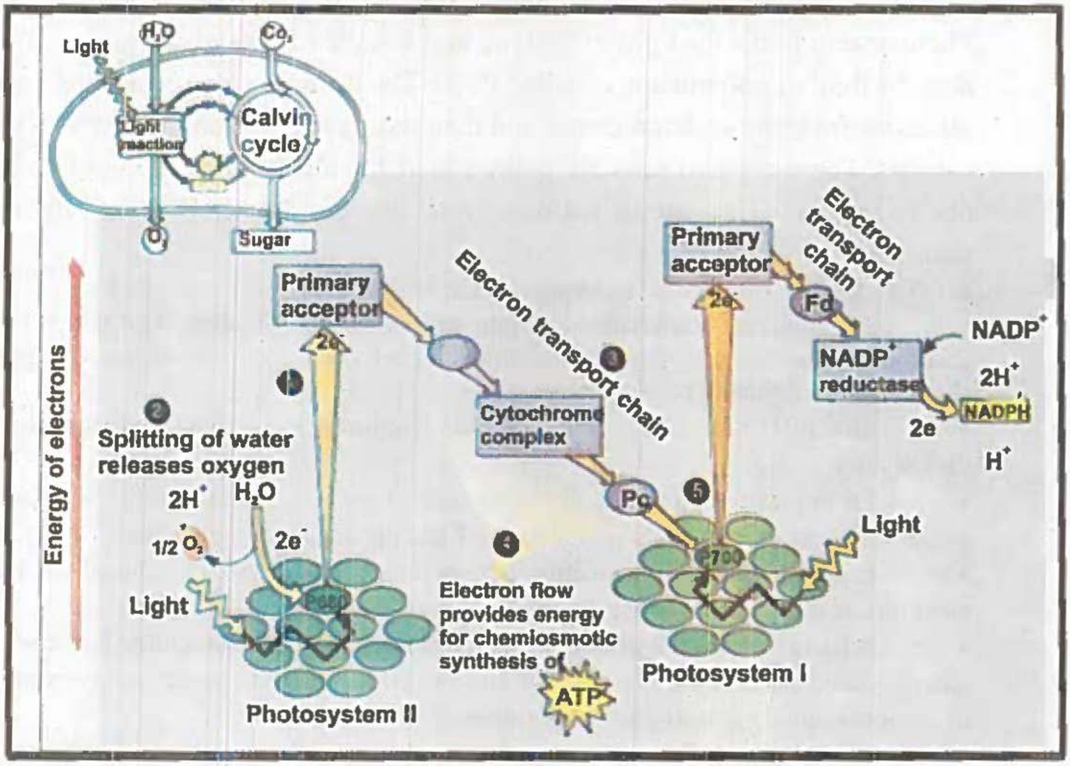


Fig: 4.7 Non Cyclic Electron Transport of Light Reaction

b. Cyclic electron transport

- Cyclic electron transport involves only photosystem I. It occurs in rare conditions if the activity of photosystem II is blocked.
- When P 700 form of chlorophyll molecule in photosystem I absorbs light, it is activated and it loses electrons, which are captured by ferrodoxin reducing substance (FRS).
- From FRS the electrons fall back to P 700 chlorophyll molecule through a series of electron carriers.
- ATP molecules are produced during cyclic electron flow.
- The electrons which are ejected from P 700 molecules are cycled back in the above electron transport therefore the process is called cyclic electron transport.
- ATP synthesis during this cyclic electron flow is called **cyclic photophosphorylation.**

Water and energy of sunlight are used in light reaction. The products of light reactions are ATP and NADPH. Both of these are transported from grana to stroma for use in dark reaction.

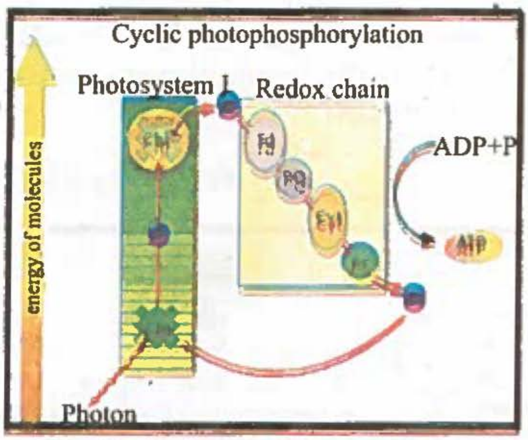


Fig: 4.8 Cyclic electron transport

4.2.2 Dark Reactions (Calvin Cycle) (Light-independent reactions)

Light independent reactions do not require direct energy of sunlight it may occur during day time but are called dark reactions so as to differentiate them from the light reactions. The sequence of dark reactions in photosynthesis was investigated by Melvin Calvin and his colleagues in 1950. They occur in a series of reactions in the stroma of chloroplast and taking the course of a cycle known as Calvin-Benson cycle.

The Calvin cycle is completed in three stages.

i. Carbon fixation

The cycle starts when ribulose bisphosphate, a 5-carbon sugar, already present in stroma reacts with CO_2 of air to form a 6-Carbon compound. This compound is unstable and soon splits up into two molecules of 3-carbon compound called Phosphoglycerate (PGA). This process is accelerated by an enzyme known as Rubisco (Ribolose biphosphate carboxylase). This is regarded as the most common protein in nature. The carbon that was part of CO_2 molecule is now a part of an organic molecule. This is called carbon fixation. PGA is regarded as the first product of photosynthesis to be identified.

RuBP + CO_2 ⟶ short lived 6-Carbon compound

6-C compound ⟶ 2PGA

ii. Reduction

PGA formed in the previous step is reduced into phosphoglyceraldehyde (PGAL) in this stage. The products of light reaction i.e. NADPH and ATP are used in the process. Each molecule of phosphoglyceric acid (PGA) receives energy from ATP and hydrogen from NADPH of light reaction, forming phosphoglyceraldehyde (PGAL) and water.

ADP and NADP return back to light reaction where ADP is converted into ATP and NADP is reduced into NADPH. In reduction process fixed carbon is reduced to a 3-carbon sugar molecule of PGAL.

$$PGA + ATP + NADPH \xrightarrow{H_2O} PGAL + ADP + P_i + NADP$$

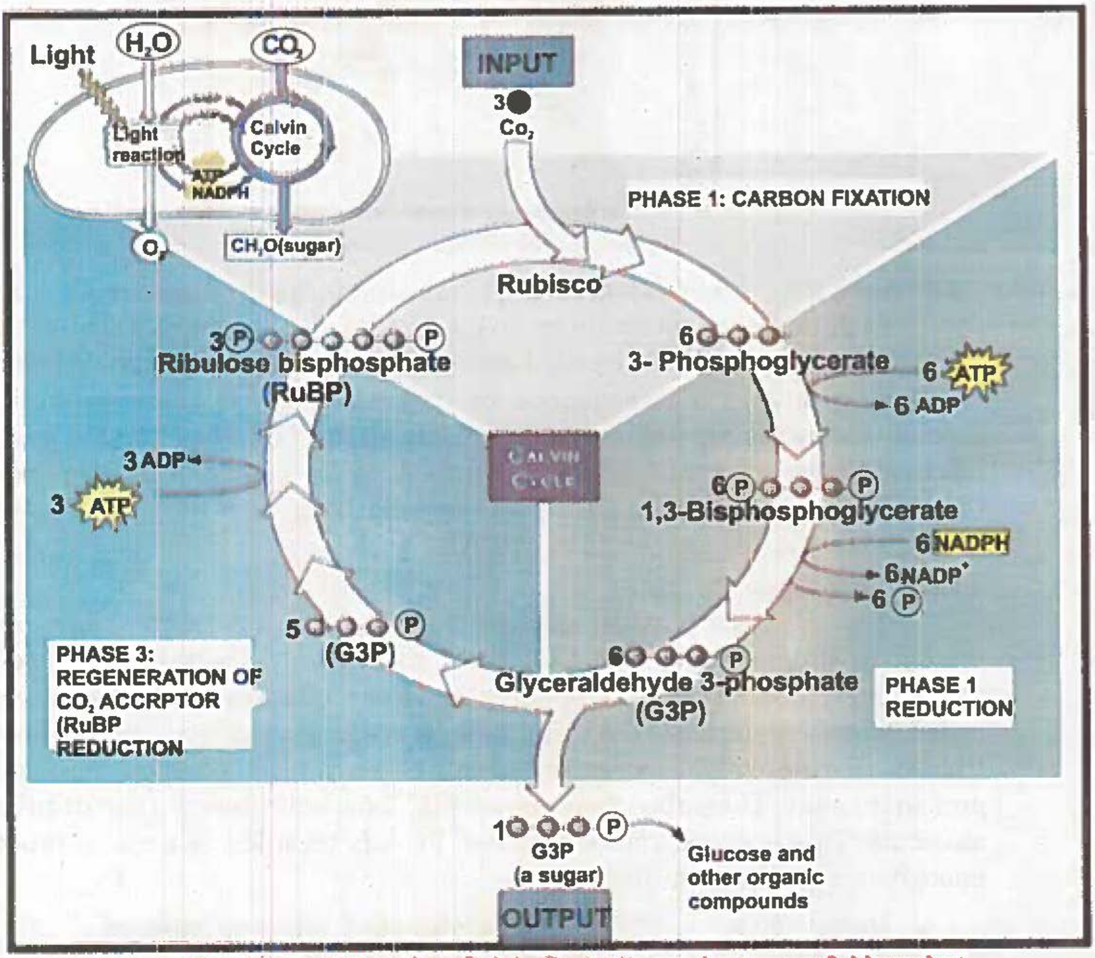


Fig : 4.9 Dark Reaction (Calvin Cycle) Occurs in stroma of chloroplast

iii. Regeneration of RuBP

In this stage RuBP molecules are regenerated so as to continue the cycle. The PGAL molecules formed in the reduction stage have many alternatives. Out of every six molecules of PGAL formed, only one molecule leaves the cycle to be used by the plant for making glucose and other organic compounds. The other five PGAL molecules are recycled to regenerate 3 molecules of five carbons RuBP by means of

several intermediates including 3-C, 4-C, 6-C, 7-C etc. This process also uses some ATP produced in light reaction. Ribulose bisphosphate (RuBP) is then available to accept CO_2 and restarts the cycle. With the regeneration of RuBP the Calvin cycle or dark reactions complete.

4.3 Respiration

Respiration is defined as oxidation-reduction processes which occur inside the living cells during which organic food is broken down and energy is released. Respiration is of two types i.e. aerobic and anaerobic

4.3.1 Aerobic respiration (Cellular Respiration)

Aerobic respiration needs free O_2. In aerobic respiration organic food is completely broken down into CO_2 and H_2O and the stored energy is released. The overall equation of aerobic respiration for glucose breakdown can be written as follows:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + 36ATP$$

Glucose and oxygen are used and carbon dioxide and water are produced. Energy is released which is used in the synthesis of ATP molecules. This is just the opposite of photosynthesis where glucose and oxygen are produced and carbon dioxide and water are used as raw materials.

Do You Know?

The overall equation of aerobic respiration gives a perception that oxygen combines with glucose molecule which is broken down into water and carbon dioxide and stored energy is released. But in fact this does not happen. Complete breakdown of glucose molecule, in aerobic respiration, occurs in three different steps i.e. glycolysis, Kreb's cycle and electron transport chain. Glycolysis occurs in cytosol (cytoplasm) while the latter two stages occur in mitochondria.

Organic food molecules are used by the living organisms as building materials and source of energy. Among the food molecules carbohydrates are the primary source of energy broken down by the living cells for the synthesis of ATP molecules. ATP are energy rich molecules also called energy currency of the cells.

The purpose of respiration is to release energy stored in organic food molecules and ATP molecules are produced. Why living cells do not acquire direct energy from the breakdown of food molecules? Why do they synthesize ATP? This is because if whole amount of energy of glucose is released it will be too great for individual reactions. This will result in heating up of the cells and also a large amount of energy will be wasted. ATP contains the right amount of energy available to the cell for its functions when it is broken down into ADP and inorganic phosphate. All living cells therefore use ATP molecules for energy requirement.

a. Glycolysis

Glycolysis is the breakdown of glucose, a 6-C molecule, in two molecules of pyruvate (3-C molecule) and a net gain of two ATP molecules. It takes place in cytosol (cytoplasm) and is common in both aerobic and anaerobic respirations. Glycolysis does not need free oxygen.

Glycolysis completes in two phases i.e. preparatory phase and oxidative phase.

i. Preparatory phase

Preparatory phase is phosphorylation of glucose by two ATP molecules.

- Glycolysis starts when glucose reacts with ATP molecule.
- ATP transfers energy and phosphate to glucose forming glucose 6-Phosphate and itself converts to ADP.
- Glucose –6 Phosphate is isomerised into Fructose-6 Phosphate.
- Fructose-6 Phsophate reacts with another ATP molecule forming fructose-1-6 bisphosphate.

Glucose +ATP ⟶ Glucose-6-Phsophate+ADP

Glucose-6 Phosphate ⟶ Fructose-6 Phosphate.

Fructose-6 Phosphate+ ATP ⟶ Fructose-1-6 bishosphate+ ADP.

- Fructose-1-6-bishosphate splits into 3-carbon Phosphoglyceraldehyde (PGAL) and dihydroxy acetone phosphate (DAP).

- Dihydroxy acetone phosphate changes to phosphoglyceryldehyde.
  Preparatory phase completes with the splitting of fructose biphosphate into PGAL and dihydroxyacetone phosphate.

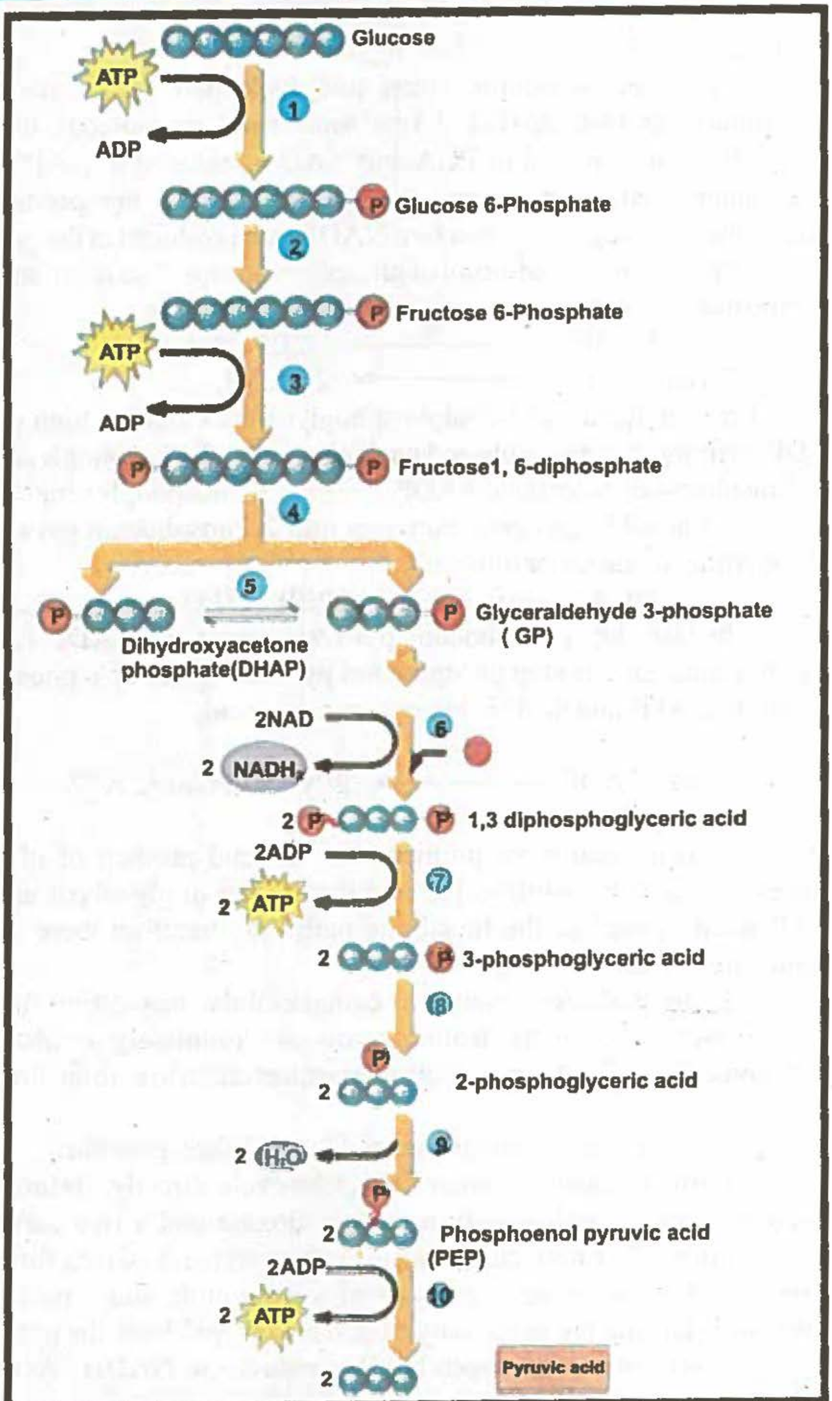


Fig: 4.10 Glycolysis

ii. Oxidative Phase

- The process begins when two hydrogen atoms are removed from 3-Phosphoglyceraldehyde (PGAL) and transferred to a molecule of NAD, a coenzyme. Thus PGAL is oxidized to PGA and NAD is reduced to $NADH_2$(this step and the subsequent steps occur twice because two PGAL are produced at the end of preparatory phase). Altogether two $NADH_2$ are produced in the process. This reaction is accompanied by the addition of phosphate groups. The resultant molecules are 1-3-bisphosphoglycerate.

$$2PGAL + 2Pi \longrightarrow 2BPGA + 2H_2$$
$$2NAD + 2H_2 \longrightarrow 2NADH_2$$

- Each molecule of 1-3-biphosphoglycerate transfers high energy phosphate to ADP forming ATP molecule and itself changes to 3-Phosphoglycerate.

1-3 bisphosphoglyceracate + ADP $\longrightarrow$ 3-Phosphoglycerate + ATP

- 3-Phosphhoglycerate converts into 2-Phosphoenol pyruvate (PEP) with the elimination of one water molecule.

$$2PGA \longrightarrow 2PEP + 2H_2O$$

- In last step phosphoenol pyruvate reacts with ADP forming an ATP and Pyruvic acid .In this step phosphoenol pyruvate gives up a phosphate group to ADP generating ATP and itself oxidizes to pyruvic acid.

$$2PEP + 2ADP \longrightarrow 2\text{Pyruvic Acid} + 2ATP.$$

- Two molecules of pyruvate are the end product of glycolysis. Since two molecules of ATP are utilized to start the process of glycolysis and four molecules of ATP are produced in the metabolic pathway, therefore there is a net gain of two molecules of ATP.

In aerobic respiration also called cellular respiration further steps occur in mitochondria. Pyruvate from glycolysis completely oxidized through linked reactions, Krebs Cycle, and electron transport chain to carbon dioxide and water.

b Conversion of pyruvate to acetyl-CoA (Linked reaction)

Pyruvate does not enter the Krebs cycle directly. Before entering the Krebs cycle pyruvate is oxidized to a carbon dioxide and a two carbon molecule called acetyl group. This molecule attaches to coenzyme A (CoA) forming a group called acetyl CoA. Coenzyme A consists of a nucleotide and a portion of one of the B vitamins. During the process hydrogen is removed from the pyruvate which is taken by NAD. By getting hydrogen NAD is reduced to $NADH_2$. Acetyl-CoA enters the Krebs cycle.

This process is called linked reaction because it links Glycolysis to the Krebs cycle.

Pyruvic Acid $\longrightarrow$ Acetyl group + CO_2 + 2H
Acetyl group + CoA $\longrightarrow$ Acetyl CoA
NAD + 2H $\longrightarrow$ $NADH_2$

Further oxidation of acetyl - CoA takes place in a cyclic manner. This cycle is called Krebs cycle.

c. Kreb's Cycle or Tricarboxylic Acid Cycle (TCA)

- In first step of cycle, Acetyl CoA produced in the linked reaction combines with pre existing oxalo acetic acid (4-C) in the presence of water molecule to form citric acid (6-C). Co-A becomes free and is ready to react with another acetyl group.

Acetyl Co.A + oxaloacetate $\longrightarrow$ Citrate + Co.A.

- Citrate is converted to isocitrate

Citrate $\longrightarrow$ Isocitrate

- Iso-citrate is oxidized to -ketoglutarate (5-C). one carbon of isocitrate is oxidized to carbon dioxide and hydrogen is removed which is picked up by NAD reducing into $NADH_2$.
- One carbon of -Ketoglutarate is oxidized into carbon dioxide which is released from the cycle. This is second CO_2 molecule produced in the Krebs cycle.
- The two carbons of the acetyl group which was entered into the Krebs cycle are oxidized into two molecules of carbon dioxide. Hydrogen atoms are released which are accepted by oxidized NAD. By accepting hydrogen atoms NAD is reduced to $NADH_2$.
- The - Ketoglutarate is converted into succinyl group (4-C).
- Co-A reacts with succinyl group forming succinyl Co-A.
- Succinyl Co-A is converted to succinate Acid (4-C) and Co- A is released.
- Some of the energy produced in the oxidation is used in the synthesis of ATP.

The energy of the substrate used in the generation of ATP is called **substrate-level phosphorylation.**

- Succinate is oxidized to fumarate (4-C). Co-enzyme FAD (flavin adenine di-nucleotide) is reduced in the reaction.
- Fumarate is converted to malate (4-C).
- Malate oxidizes to oxaloacetate. A molecule of NADH is produced during this step. The oxaloacetate is now able to react with another acetyl Co-A and continue the cycle.

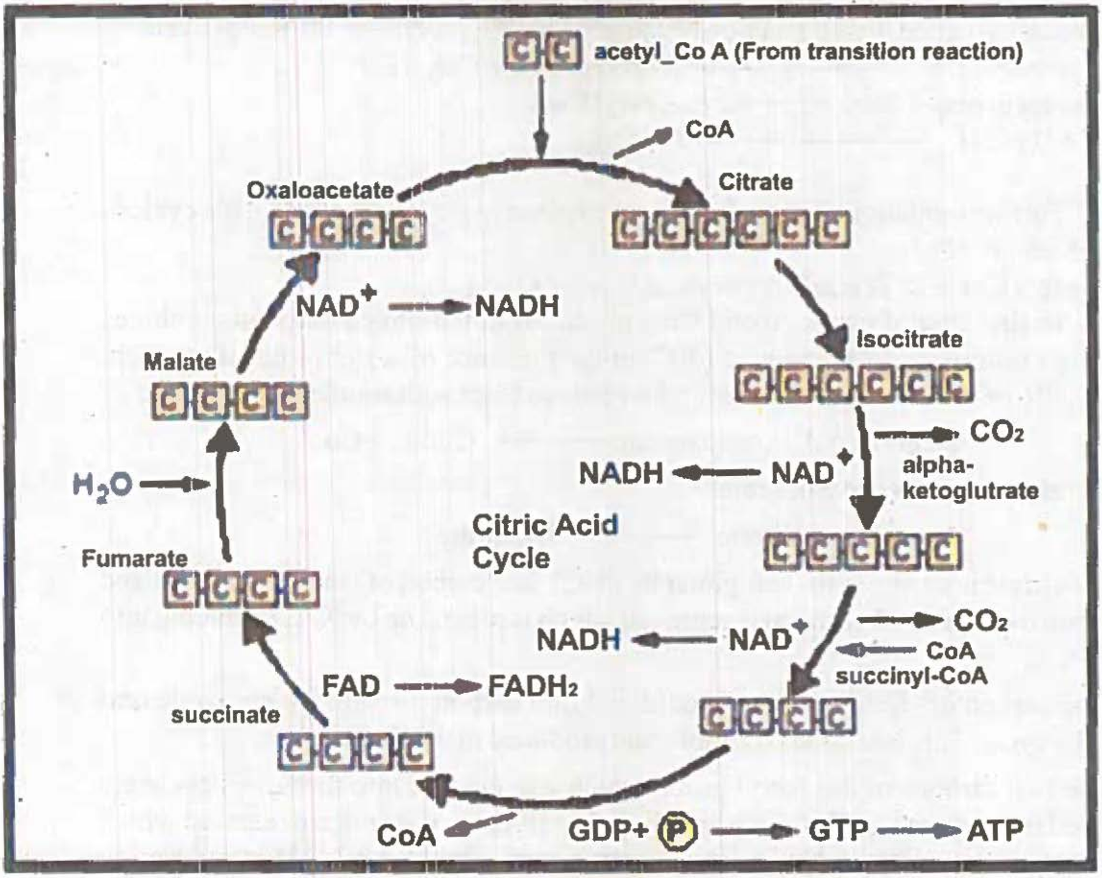


Fig: 4.11 Kreb's cycle.

For Your Information

The step wise oxidation of each acetyl Co-A in the Krebs cycle gives rise to two molecules of CO_2 and much of the free energy released during this oxidation is stored in the form of reduced $NADH_2$ and $FADH_2$. In the process an ATP is generated by a substrate level phosophrylation. Over all eight molecules of $NADH_2$, two molecules of $FADH_2$ and two molecules of ATPs are formed from one glucose molecule in mitochondrial matrix. It should be remembered that as two pyruvate are formed from one glucose molecule in glycolysis therefore there are two turns of Krebs cycle for one glucose molecule.

d. Respiratory Electron transport Chain

The last step in aerobic respiration is the oxidation of reduced coenzymes $NADH_2$ and $FADH_2$ produced in glycolysis and Krebs cycle by molecular oxygen. The pairs of hydrogen atoms released from glucose during glycolysis and Krebs cycle of aerobic respiration are not received directly by oxygen but pass along a series of electron carriers called coenzymes and cytochromes. This series of electron carriers constitute respiratory electron transport chain. The final electron acceptor at the end of the electron transport chain is oxygen forming water. Various molecules involved in the electron transport are $NADH_2$, $FADH_2$ coenzyme Q, cytochrome b (Cyt.b), cytochrome c (Cyt.c), cytochrome a (Cyt.a) and Cytochrome a_3 (Cyt.a_3). The coenzyme Q and cytochromes are alternately reduced and oxidized. Electrons are passed along a series of carriers as they lose energy at each transfer. Some of this energy is used in the formation of ATP from ADP and inorganic phosphate. In the electron transport chain each next molecule is at lower energy level than the previous one. At the end oxygen accepts electrons and hydrogen to form water.

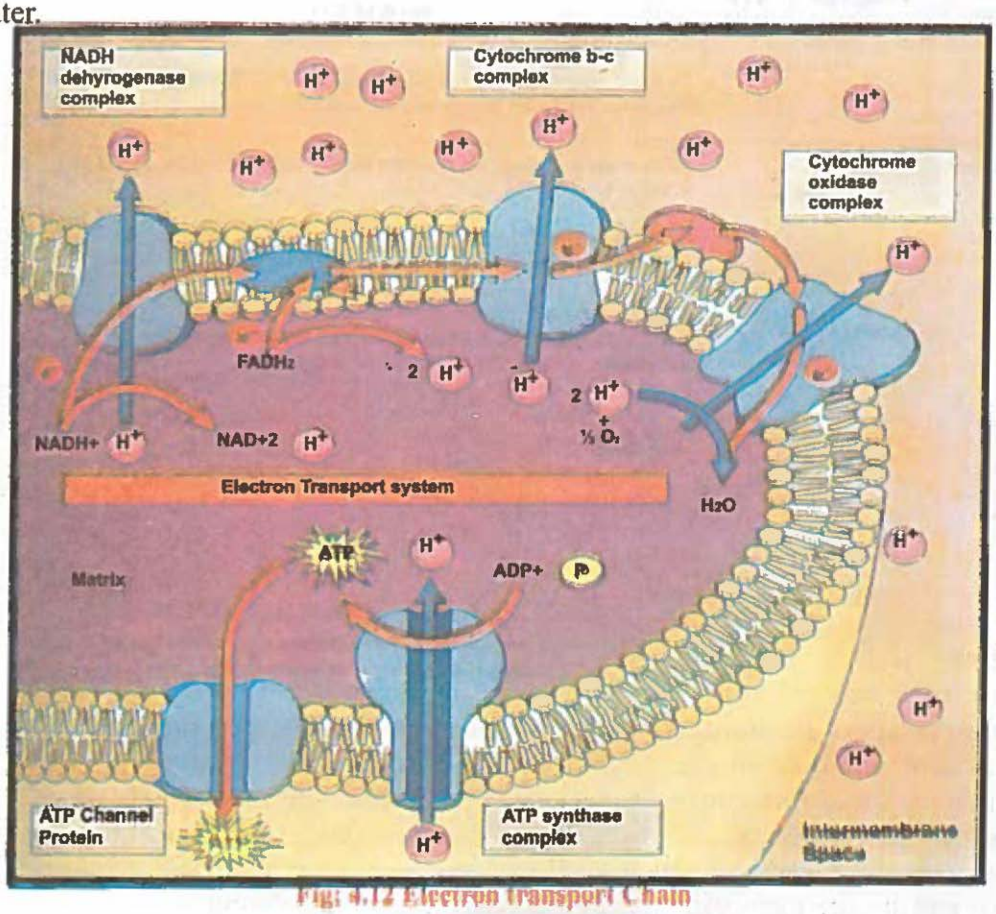


Fig: 4.12 Electron transport Chain

Chemiosmotic ATP Synthesis

The synthesis of ATP from ADP and inorganic phosphate in the electron transport system through the joint event of chemical and osmotic processes is called chemiosmotic ATP synthesis. Chemiosmotic theory of ATP synthesis suggests how ATP formation is coupled with the energy release in the electron transport system. Mitochondria are surrounded by double membrane. The outer membrane is smooth while the inner membrane forms enfolding which are shelf-like projections or protuberances called cristae. The cristae are present in the inner chamber or mitochondrial matrix that is filled with a gel-like substance. The carriers of electron transport system are present on the cristae. A space is present between the outer and inner membrane called intermembrane space.

Table No: 4.1 Production of ATPs in respiratory chemical pathways.

Pathway	Coenzyme yield	ATP yield	Source of ATP
Glycolysis preparatory phase		-2	To begin glycolysis requires the input of two ATP from the cytoplasm. This is the activation energy needed to start this reaction.
Glycolysis pay-off phase		4	ATPs made by glycolysis. Note the Net Yield for glycolysis would be 2ATPs (4 ATP-2ATP).
	2 NADH (Ext)	4 (6)	These molecules are created by glycolysis, but they can only be converted into ATP in the mitochondrial electron transport chain. This requires them to enter the mitochondria. A step that is free in some organisms, and costs 2ATP in othem. This is what causes the differences in the Net yield of aerobic respiration.
Pyruvate Oxidation	2 NADH (Int)	6	ETC (Electron Transport chain)
Krebs cycle		2	Substrate-level phosphorylation
	6 NADH	18	ETC
	2 $FADH_2$	4	ETC
Total yield		36 (38) ATP	From the complete breakdown of one glucose molecule to carbon dioxide and oxidation of all the high energy molecules.

During the passage of electrons through the electron transport system certain carriers of the system pump hydrogen ions from the mitochondrial matrix into the intermembrane space. As result hydrogen ions accumulate on the outside of the inner membrane in the intermembrane space. Difference of hydrogen ion concentration increases across the membrane which develops a gradient of hydrogen ions between the matrix and the intermembrane space i.e. across the inner membrane.

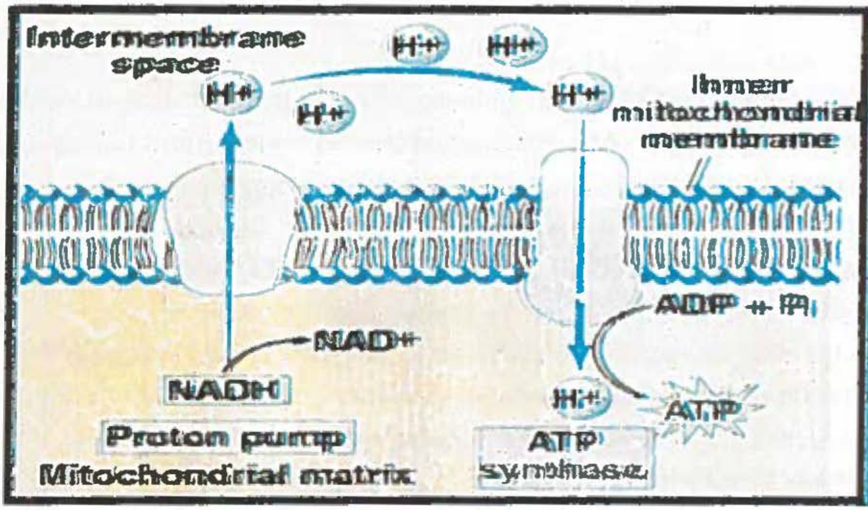


Fig : 4.13 Chemiosmotic ATP synthesis

Hydrogen ions diffuse down the inner membrane through electrochemical gradient from the intermembrane space into the matrix. The passage of hydrogen ions through the membrane is coupled to ATP synthesis from ADP and inorganic phosphate through ATP synthase complex. This process of ATP synthesis is called chemiosmosis because electrochemical and osmotic events are involved.

Cellular Respiration of Proteins and Fats

Cells degrade mostly glucose to release energy. However cells can oxidize and degrade other food molecules such as proteins and fats to release energy.

Fats, Protein and Glucose Metabolism

Proteins are broken down to amino acids. Amino group is removed from amino acids forming ammonia and the remaining molecule enters the Krebs cycle. Entry point to the Krebs cycle depends on the number of carbon atoms of the entering molecule.

When fat is used as energy source it is hydrolyzed into glycerol and three fatty acids. Glycerol (a 3-C compound) is converted to PGAL which enters the process of respiration into the glycolytic pathway. Each fatty acid is degraded into two carbon fragments acetyl groups which enter into Krebs cycle. For example palmatic acid is a fatty acid with 16 carbon atoms. It breaks down into eight acetyl groups. It is estimated that these eight acetyl groups would generate net 129 ATP molecules. Because of very large number of production of ATP molecules fats are regarded as very efficient form of stored energy.

4.3.2 Anaerobic Respiration

The incomplete breakdown of glucose without the utilization of oxygen is called anaerobic respiration. Anaerobic respiration (Fermentation) occurs in the absence of oxygen. It involves incomplete breakdown of organic food molecule and only a small amount of energy is released. Pyruvate formed in glycolysis has two pathways. In human cells it depends on the availability of oxygen. If oxygen is available then pyruvic acids is completely degraded into CO_2 and water in mitochondria i.e. aerobic respiration. If oxygen is not available then anaerobic respiration continues and fermentation occurs. The process of fermentation consists of two steps i.e. glycolysis and the reduction of pyruvate into alcohol or to lactate. Anaerobic respiration is of two types.

a. Lactic Acid Fermentation

This form of fermentation occurs in muscle cells of human and in many microorganisms. It completes in two steps. In the first step glucose is broken down into pyruvic acid which is basically glycolysis. In the next step pyruvic acid is reduced by $NADH_2$ into lactic acid. Compared to aerobic respiration which yields 36 ATP molecules from the breakdown of one glucose, anaerobic respiration yields only 2 ATP molecules. Despite its low yield of ATP, anaerobic respiration has its importance because of rapid production of ATP (energy) when demanded.

A) $$\text{Glucose} + 2ATP \longrightarrow \text{Pyruvic acid} + 4ATP$$

B) $$\underset{\text{Pyruvic Acid}}{2(C_3H_4O_3)} \xrightarrow{2NADH \quad 2NAD} \underset{\text{Lactic Acid}}{2(C_3H_6O_3)}$$

b. Alcoholic Fermentation

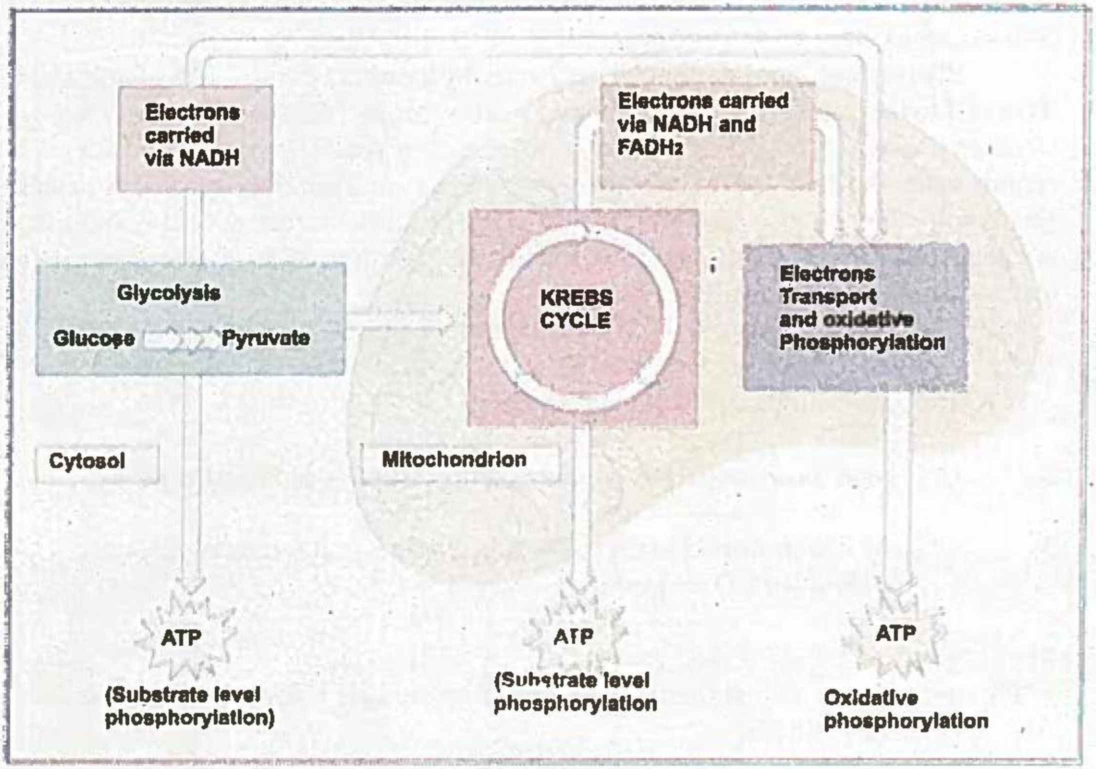
Alcoholic Fermentation is brought about by microorganisms.

This type of anaerobic respiration also completes in two steps.

First step is the same glycolysis during which glucose molecule is broken down into two molecules of pyruvic acid and NAD is reduced to $NADH_2$.

In the next step $NADH_2$ gives hydrogen to pyruvic acid, which is converted into ethyl alcohol and CO_2. In alcoholic fermentation also 2 ATP molecules are produced from one glucose molecule. This is called alcoholic fermentation because alcohol is produced at the end.

$$\underset{\text{Pyruvic Acid}}{(C_3H_4O_3)} \xrightarrow{\nearrow 2CO_2} \underset{\text{Acetaldehyde}}{2(C_2H_4O)} \xrightarrow{2NADH \;\; 2NAD} \underset{\text{Ethyl Alcohol}}{2\,(C_2H_5OH) + ATP}$$



. Fig: 4.14 Over view of respiration process

4.4 Photorespiration and its effects

Photorespiration is defined as the process in which oxygen combines with ribulose biphosphate (RuBP) in the presence of sunlight and CO_2 is produced. The process is called photorespiration because in the presence of light (photo), oxygen is taken up and CO2 is evolved (respiration).

Photosynthesis needs optimum concentration of the requirements for normal functioning. If however one of the requirement is present in less concentration than the optimum, the process of photosynthesis is affected and slows down.

In the Dark reaction of photosynthesis, normally CO_2 combines with RuBP (carboxylation) forming PGA molecules. The process occurs in the presence of an enzyme called ribulose biphosphate carboxylase (rubisco). This enzyme can act both as carboxylase and oxygenase. The reaction depends or the concentration of CO_2 and O_2. If the concentration of CO_2 is more, then rubisco combines with CO_2 and photosynthesis proceeds normally. On the other hand if the concentration of O_2 is more, then rubisco combines with O_2 and photorespiration occurs. (Rubisco can act both as carboxylase as well as oxygenase).

Plants have stomata for the exchange of gases. Diffusio. ' water vapours from leaf to the external environment also occurs through the ston in dry and hot weather plants close up stomata so as to conserve water. In such condition CO_2 cannot enter the leaf and O_2 cannot leave it. Dry and hot conditions are usually accompanied by intense sunlight therefore light reaction occurs with maximum rate which results in maximum use of CO_2. Since concentration of CO_2 lowers down in the leaf and photorespiration proceeds.

The following steps are involved in photorespiration:

1. Oxygen combines with RuBP (present in stroma of chloroplast) and a compound called Glycolate is produced.

   RuBP + O_2 ⟶ Glycolate

2. Glycolate is converted into glycine (simplest amino acid) in the pero me.

   Glycolate ⟶ Glysine

3. Glycine is transported to mitochondria where it is converted into seri a molecule of CO_2 is produced.

   Glysine ⟶ Serine + Co_2

4.4.1 Disadvantages of Photorespiration (Consequences)

1. Photorespiration is just the reverse of photosynthesis hampering the fixation of CO_2photosynthesis.
2. The process wastes energy and does nothing to serve the needs of the plant.

4.5 C_4 Photosynthesis

In normal process of photosynthesis a 3C carbon compound called PGA is formed as the first detected product of photosynthesis (carbon dioxide fixation) and therefore these plants are called C_3 plants. There are some plants growing in dry and hot conditions produce a 4C carbon compound called oxaloacetate as the first product of carbon dioxide fixation in dark reactions of photosynthesis.

These plants are called C_4 plants and this type of photosynthesis is called C_4 photosynthesis. C_3 plants use rubisco to react CO_2 with RuBP. On the other hand C_4 plants use another enzyme called pepco (phosphoenolpyruvate carboxylase) to fix CO_2 to a compound called phosphoenolpyruvate (PEP) and oxaloacetic acid (OAA). This OAA is reduced to another molecule called malate. The malate carries CO_2 to the special type of cells called bundle sheath cells where Calvin cycle proceeds.

In C_3 plants chloroplasts are present only in mesophyll cells of leaf. However in a C_4 plant chloroplasts are present both in mesophyll cells and in bundle sheath cell. In a C_3 plant all the mesophyll cells carry out Calvin cycle by fixing CO_2 and producing glucose. In a C_4 plant the mesophyll cells only fix CO_2 by using pepco while the bundle sheath cells carry out Calvin cycle producing glucose.

This is a special condition evolved by C_4 plants so as to prevent photorespiration even in dry and hot environment as pepco does not bind to O_2 irrespective of the concentration of CO_2. Examples of C_4 plants are sugar cane, maize etc.

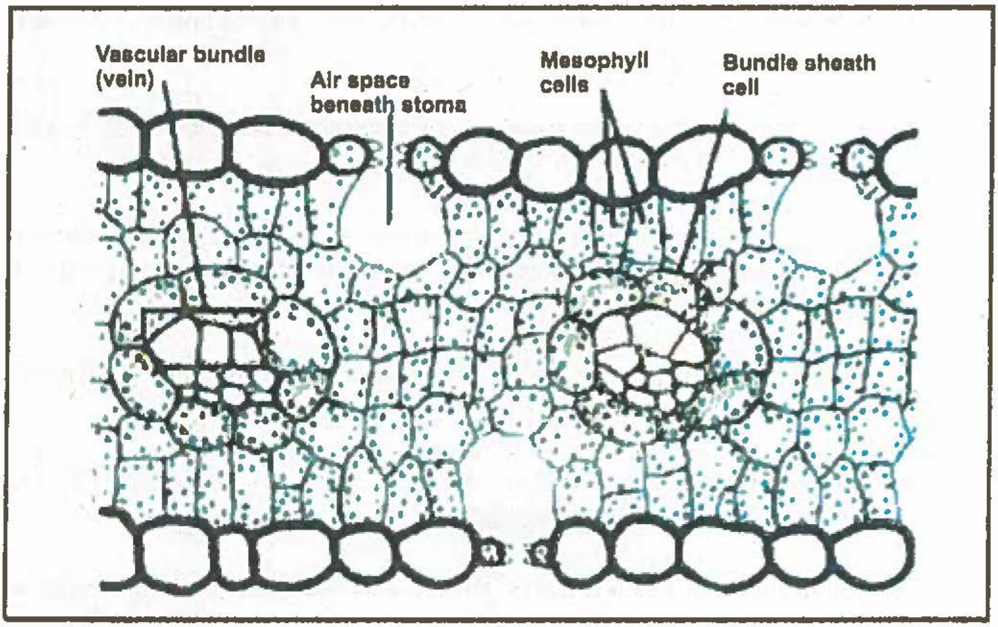


Fig: 4.15 Portion of a cross section of a leaf with C_4 photosynthesis.

In C_4 plants the rate of photosynthesis remains high even when the stomata are closed and temperature is high. The rate of CO_2 fixation is also high as compared to C_3 plants. C_4 cycle is basically an adoptability of C_4 plants to carry out CO_2 fixation in dry and hot condition and to reduce the rate of photorespiration.

KEY POINTS

- Bioenergetics is the study of those processes by means of which living organisms store, use and release energy.
- Photosynthesis is a process in which the green plants convert light energy into chemical form.
- The organic molecules of food are broken down and their energy isreleased in the process ofrespiration.
- ATP is a key molecule of biological world which, is the main source ofenergy.
- Photosynthesis has two sets of reactions. During light reactions ATP and $NADH_2$ are produced, as end products and these reactions need sunlight.
- The products of light reactions are used in the dark reactions, which does not need light energy.
- The oxidative-reductive reactions of respiration release energy stored inthe food molecules.
- Respiration may be aerobic or anaerobic (fermentation).In anaerobic respiration only 2ATP molecules are produced and its end products may be lactic acid or ethyl alcohol and CO_2.
- The phase of glycolysis is common in aerobic and anaerobic respiration.
- Kerbs cycle occurs in aerobic respiration, ATP, $NADH_2$ and $FADH_2$ are produced during this cycle.
- Photorespiration is a process that reduces the yield of photosynthesis, because the active site of rubisco accepts O_2 in place of CO_2 and generates no ATP. This usually occurs on hot, dry days when stomata are closed and the O_2 concentration in the leaf exceeds that of CO_2, thereby competing for a common active site.

EXERCISE ?

A. Choose the correct answer to the following questions.

1. The ultimate source of energy for maintenance of life on earth is:
   a. carbohydrate b. ATP
   c. sun d. mitochondria
2. In which compartment of the plant cell do the light-independent reactions of photosynthesis take place?
   a. Thylakoid b. Stroma
   c. Outer membrane d. Mesophyll
3. What would happen if the process of photosynthesis stops on earth?
   a. There will be more food
   b. No problem to living organisms
   c. No life on earth possible
   d. Living organisms will start using direct energy from sun
4. Identify in the following which is not a limiting factor for photosynthesis.
   a. light intensity
   b. temperature
   c. concentration of carbon dioxide
   d. concentration of oxygen
5. Which of the following molecule is regenerated from phosphoglyceraldehyde in Calvin cycle?
   a. Phosphoglyceric acid b. Plastoquinone
   c. Ribulose biphosphate d. CO_2
6. The end products of non-cyclic electron pathway is:
   a. ATP b. $NADPH_2$
   c. ATP and $NADPH_2$ d. $FADH_2$
7. The final electron acceptor in non-cyclic electron pathway is:
   a. ATP b. NADP
   c. $FADH_2$ d. ADP
8. ATP generated within the Krebs cycle is called:
   a. photophosphorylation b. oxidative phosphorylation
   c. substrate-level phosphorylation d. electron transport chain
9. The electron carriers of chloroplast are present in:
   a. matrix of stroma b. inter-membrane space
   c. within the thylakoid space d. within its thylakoid

EXERCISE

10. In a eukaryotic cell the Krebs cycle occurs in:
    a. cytosol b. nucleus
    c. chloroplast d. mitochondria
11. Within the mitochondria the proton gradient develops across the:
    a. outer membrane b. inner membrane
    c. matrix d. inter membrane space
12. Which of the following generates more energy in aerobic respiration?
    a. Glucose b. Triglyceride
    c. Protein d. Sucrose
13. Phosphoenol pyruvate carboxylase is used in C4 Plants to :
    a. Fix CO_2 b. Fix O_2
    c. Reduce RuBP d. Reduce pyruvate molecule

B. Write short answers to the following questions

1. Define glycolysis.
2. What is photorespiration?
3. What do you mean by chemiomosis?
4. State the role of carbondioxide as one of the raw materials of photosynthesis.
5. Differentiate between the absorption spectra of different photosynthetic pigments.
6. What is the main difference between cyclic and non cyclic photo

C. Write in detail the answers of the following questions.

1. Describe the role of sunlight in the process of photosynthesis.
2. Give an account of the events of non-cyclic electron pathway.
3. Write down the main steps of Calvin cycle.
4. Write a detailed note on the various steps of Kreb's cycle.
5. What is photorespiration and what are its disadvantages?

Projects:

- Develop the graphical interpretation of the wavelengths of light along with the percentage absorption by chlorophyll 'a' and 'b'.
- Develop a flow chart for explaining the events of the light-independent reactions.
- Draw the flow charts showing the events of glycolysis and Krebs cycle.
- Illustrate the net energy output during glycolysis, oxidation of pyruvate and Krebs cycle.

Chapter 5

Acellular Life

At the end of this chapter students will be able to:

- Justify the status of viruses among living and non-living things.
- Trace the history of viruses since their discovery.
- Classify viruses on the bases of their hosts and structure.
- Explain the structure of a model bacteriophage, flu virus and HIV.
- Justify why a virus must have a host cell to parasitize in order to complete its life cycle.
- Explain how a virus survives inside a host cell, protected from the immune system.
- Determine the method a virus employs to survive/ pass over unfavorable conditions when it does not have a host to complete the life cycle.
- Describe the Lytic and Lysogenic life cycles of a virus.
- Outline the usage of bacteriophage in genetic engineering.
- Explain the life cycle of HIV.
- Justify the name of the virus i.e., "Human Immunodeficiency Virus" by establishing T-helper cells as the basis of immune system.
- Reason out the specificity of HIV on its host cells.
- List the symptoms of AIDS.
- Explain opportunistic diseases that may attack an AIDS victim.
- Describe the treatments available for AIDS.
- List some common control measures against the transmission of HIV.
- Describe the causative agent, symptoms, treatment and prevention of the following viral diseases: hepatitis, herpes, polio and leaf curl virus disease of cotton.
- List the sources of transmission for each of the above-mentioned diseases.
- Assess from the given data the economic loss from viral infections.(cotton leaf curl virus disease and bird flu virus) in Pakistan.
- Describe the structure of prions and viroids.
- List the diseases caused by prions and viroids.

Introduction

Viruses are abundant in nature and can infect and parasitize all living organisms from bacteria to mammals. They are considered to be very simple biological entities composed of a small number of macromolecules produced by, and thus derived from, the organism they infect. Viruses cause many diseases of international importance. Amongst the human viruses, smallpox, polio, influenza, hepatitis, human immunodeficiency virus (HIV-AIDS), measles and the Severe acute respiratory syndrome(SARS), coronavirus are particularly well known. While antibiotics can be very effective against diseases caused by bacteria, these treatments are ineffective against viruses and most control measures rely on vaccines or relief of the symptoms to encourage the body's own defense system. Viruses also cause many important plant diseases and are responsible for huge losses in crop production and quality in all parts of the world.

For Your Information

In just ten minutes, a virus may take over a cell, copy itself hundreds of times, and kill the cell. Some viruses have a calculated replication time of about 70 seconds. By comparison, the fastest bacterial replicators only double their biomass every 20 minutes or so.

5.1 Status of viruses

Viruses lie on the border line between living and non living things. Viruses are considered as living because viruses possess DNA or RNA. They have the ability of reproduction. They can undergo mutation and genetic recombination and also possess the ability to infect other living things and show irritability.

Apart from these living characters viruses possess some non living characters. They are sub cellular or non cellular structure. They do not respire or excrete, can be crystallized and stored in much the same way as chemicals.

5.2 Discovery of the virus

By the late 1800's pioneer bacteriologists like **Louis Pasteur, Robert Koch** had demonstrated that bacteria cause many diseases of man and other organisms. However, causal agents of some diseases puzzled them. One such disease was tobacco mosaic disease. The agent of this disease could be transmitted from an

infected organism to a healthy organism of the same kind . This was first demonstrated in 1892 by a Russian biologists named **Iwanowsky**.

By 1900 similar disease, producing substances had been discovered in many organisms, both plants and animals. In 1898 it was demonstrated that virus from the blisters produced on the diseased stock could transmit foot and mouth disease of cattle. It was given the name filterable viruses, the viruses that can pass through a filter from which bacteria cannot pass.

By 1930 most people believed that the viruses are small particles not visible through compound microscope. In 1935 **W.M. Stanley** prepared an extract of tobacco mosaic virus. Under the compound microscope, the isolated viruses appeared as silvery crystals composed of many rod – shaped structures. Isolated, purified extracts from the cells of the hosts revealed that TMV as dead particles. This started a debate whether viruses living or dead? **W.M. Stanley** took purified TMV, dissolved it in water and rubbed it on the leaves of healthy tobacco plants. The leaves soon showed the mottle condition, characteristics of TMV disease. It was found that viruses had reproduced itself in living cells of the host. This proved that viruses had some living charactertics

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5.3 Classification of Viruses

Viruses can be broadly classified based on morphology and the type of host they infect. On the basis of morphology there are three classes of viruses,

a. Spherical Virus. e. g. Polio virus

b. Tadpole shaped virus. e.g. Bacteriophage.

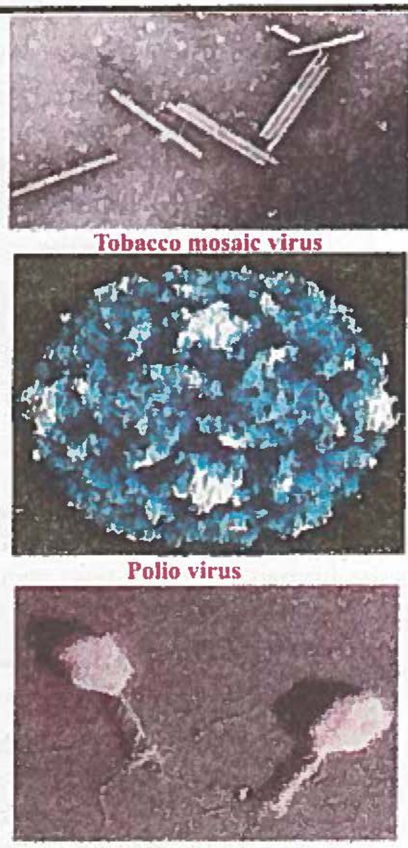
c. Rod shaped virus. e.g. tobacco mosaic virus.

Viruses can be classified on the basis of host:

a. Animals viruses: They are parasites of animals and human beings and causes diseases in them. Common diseases in man are polio, small pox, measles, mumps and influenza etc.

b. Plant viruses: These are parasite on plants and cause diseases in them.

c. Bacteriophage (phage): This virus is parasite only on bacteria.



Tobacco mosaic virus

Polio virus

Bacteriophage

Fig; 5.1 Different Shapes of Viruses

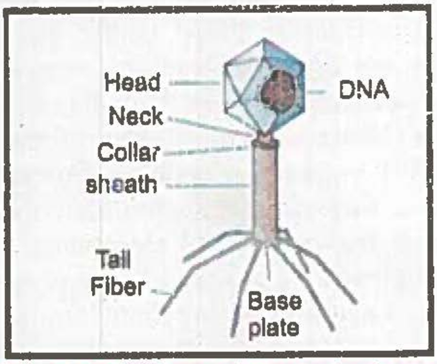
5.4 Structure of the some Representative Viruses

5.4.1 Structure of Bacteriophage

Bacteriophage (phage) are obligate intracellular parasites that multiply inside bacteria by making use of the host biosynthetic machinery. Bacteriophages have many different sizes and shapes. The basic structural features of bacteriophage are as follows:

1. Size -. Most phages range in size from 24-200 nm in length.

2. Head or Capsid - All phages contain a head structure which can vary in size and shape. Some are icosahedral (20 sides) others are filamentous. The head or capsid is composed of many copies of one or more different proteins. Inside the head is found the nucleic acid (DNA or RNA). The head acts as the protective covering for the nucleic acid.



Fig; 5.2 Structure of Bacteriophage

3. Tail - Many but not all phages have tails attached to the phage head. The tail is a hollow tube through which the nucleic acid passes during infection. The size of the tail can vary and some phages do not even have a tail structure.

In the more complex phages like T4 have a base plate and one or more tail fibers attached to it. The base plate and tail fibers are involved in the attachment of the phage to the bacterial cell. Not all phages have base plates and tail fibers. In these instances other structures are involved in attachment of the phage particle to the bacterium.

5.4.2 The Structure of HIV

HIV stands for Human Immunodeficiency Virus. Like all viruses, HIV cannot grow or reproduce on its own. In order to make new copies of itself it must infect the human cells. Outside of a human cell, HIV exists as roughly spherical particles; the surface of each particle shows numerous spikes.

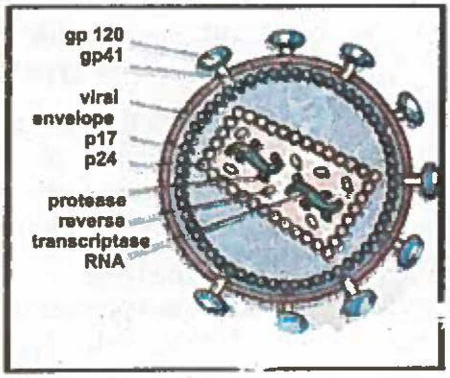
Tidbit

An HIV particle is around 100-150 billionths of a metre in diameter. That's about the same as: 0.1 microns 4 millionths of an inch one twentieth of the length of an E. coli bacterium one seventieth of the diameter of a human CD4+ white blood cell.

Unlike most bacteria, HIV particles are too small to be seen through an ordinary microscope. However they can be seen clearly with an electron microscope. HIV particles surround themselves with a coat of lipo protein known as the viral envelop (or membrane). Projecting from this are around 72 little spikes, which are formed from the proteins (gylcoprotein) gp120 and gp41. Just below the viral envelope is a layer called the matrix, which is made from the (matrix) protein p17.

The proteins gp120 and gp41 together make up the spikes that project from HIV particles, while p17 forms the matrix and p24 forms the core.

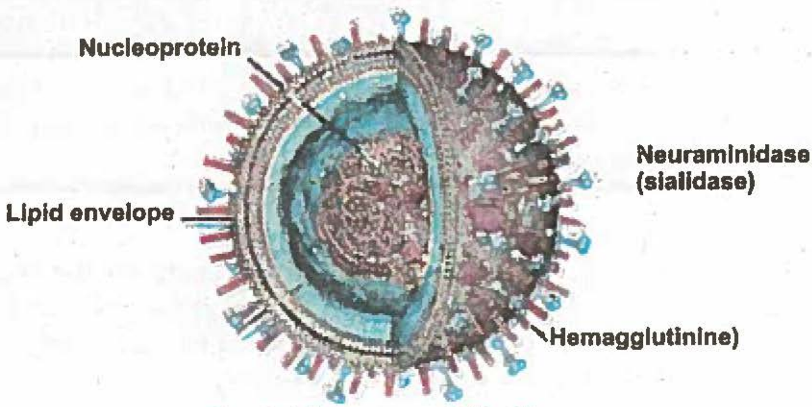
The viral core (or capsid) is usually bullet-shaped and is made from the ein p24. Inside the core are three enzymes quired for HIV replication called reverse transcriptase, integrase and protease. Also held within the core is HIV's genetic material, which consists of two identical strands of RN belongs to a special class of viruses call viruses.



Fig; 5.3 Human Immunodeficiency virus

5.4.3 Structure of F

Influenza is an R us which may exist in different shapes from round alls to long, spaghetti-li filaments. The genome of this virus is associated with five different viral protein and is surrounded by a lipid membrane, which means that influenza belongs to the "enveloped" group of viruses. Eight separate pieces of bonucleic acid (RNA)make up the influenza virus genome and each piece of RNA cifies the amino acid sequence of one and sometimes two of the virus's proteins.



Fig; 5.4 Structure of Flu Virus

5.5 Parasitic Nature of Viruses

5.5.1 Virus Evasion of Immune Responses

Viruses have evolved many mechanisms by which they can tackle the immune system. Some of the prominent ways are as under:

- Any foreign agent entering the body faces phagocytosis which is carried out by macrophages and neutrophils. In certain viruses capsules, protein, and fibrin coats do not bind the adhesion molecules used by macrophages and neutrophils so they are safe from being phagocytosed
- Some viruses cover, like bacteria, their cell walls with host proteins. So in this way body immune system is unable to recognize them as foreign body.
- Many viruses produce mutants (antigenic variations) at regular basis. And vaccine developed to control the spread of one mutant virus becomes ineffective against the new mutant so controlling them is a continuous challenge. For example influenza virus and HIV.

5.5.2 Virus and the Host

Viruses do not possess any life sustaining characteristics, and do not require any nutrients. In fact, without proper host viruses lie dormant indefinitely. However, viruses are specific to a certain kind of cell. They also have preferred ways of entrance into their hosts. A virus' method of entry is very specialized, and it is one of the main ways a virus is able to locate it's victims. Take, for example, a virus that targets host cells located in the stomach. If a person inhaled such virus particles they would not be harmed. On the other hand, if any virus molecules were ingested into the stomach, the hosts would immediately be infected. Some viruses even require cells to be in certain stages of life. These viruses may prefer actively dividing cells or cells that are younger.

Interpreting and Recording

Record the symptoms of flu in any individual. Make a list of names of at least five viruses each in plants and animals that are specific for a specific host.

5.6 Life Cycle of a Bacteriophage

The virus that infects and becomes parasite on the bacterium is called Bacteriophage. There are many strains of the phage but only one kind of phage will attack only one strain or one species of bacteria. There are two types of life cycles of the phage namely lytic cycle and lysogenics cycle.

a. Lytic cycle

In this cycle the phage is regarded as virulent or master and the bacterial cell(host)is regarded as slave. In lytic cycle the phage first attaches itself by its tail to the cell wall of bacterium at a point called **receptor site**. The phage contains an enzyme called lysosome, which digest the cell wall of bacterium. Thus an opening is formed in the bacterial cell wall. The phage contracts and injects its DNA inside the host while the protein coat and the tail remain outside.

Inside the bacterial cell the phage DNA takes over the biosynthetic machinery of the host to synthesize its own DNA and protein molecule. The phage multiplies and increases in number. The daughter phages exert pressure on the cell wall of bacterium. Thus the bacterial cell ruptures (lysis occurs) and release the daughter phages, which are now ready to attack new bacteria and start their cycle again. This type of life cycle in which the bacterium cell bursts is called lytic cycle of the phage.

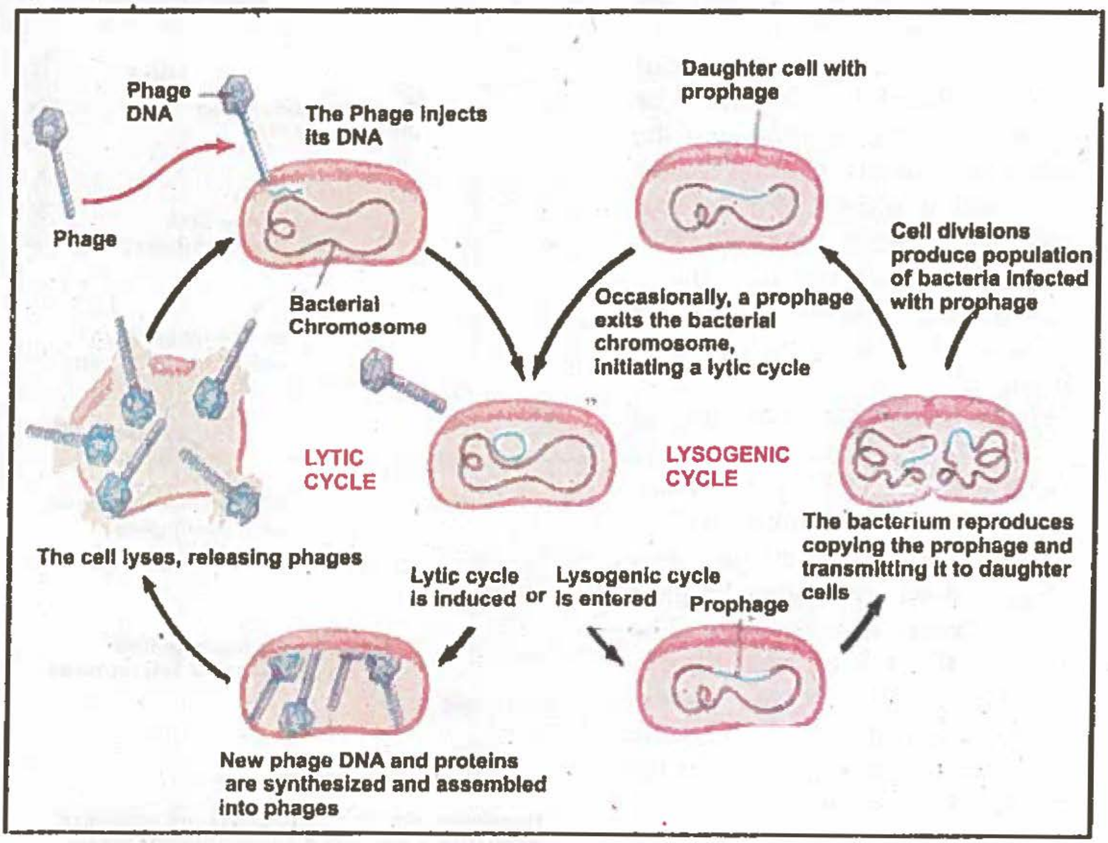


Fig:5.5 Conversion of lytic and lysogenic cycle

b. Lysogenic cycle

In this cycle, the phage does not kill or destroy the bacterium(host). Both the phage and bacterium live and multiply in a peaceful coexistence. In this case the phage becomes a harmless guest and the bacterium acts as a host. Sometimes when the phage DNA enters the bacterial cell, instead of taking over the control of biosynthetic machinery of the host it becomes associated and mixed up with the bacterial chromosome in a friendly atmosphere. In this condition the bacterium continues to live and reproduces normally. The phage DNA passes to each daughter cell of bacterium in all successive generations.

Thus the number of phages increases without any harm or damage to the bacterium cell. Therefore this relation is called guest- host relation. This type of cycle is called lysogenic cycle. Sometimes, however, the phage-DNA is separated from the bacterial chromosomes and becomes re-activated to become virulent and hence destroy the bacterial cell and starts the lytic cycle again.

5.7 Usage of Bacteriophage in Genetic Engineering

Isolated genes cannot replicate themselves, a gene to be cloned must be inserted into the DNA of suitable cloning vector like bacteriophages. Virus DNA molecule is used to transfer a DNA fragment from a test tube into a living cell. Cloning vectors are capable of multiplying inside of living cells.

Phages can be used as cloning vectors to introduce recombinant DNA into bacterial cells. Once inside a cell, the recombinant DNA may begin replication and new phages, each containing the gene of interest, are formed. The bacterial cellular machinery synthesizes the vector system proteins and DNA, but the bacterium is destroyed when the phages are released.

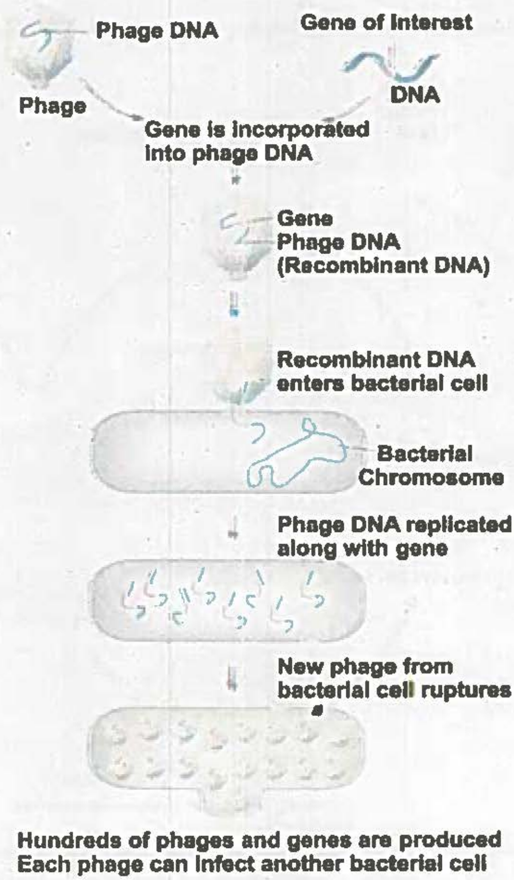


Fig 5.6 Usage of bacteriophage in genetic engineering

5.8 AIDS and HIV Infection

AIDS stands for Acquired Immune Deficiency Syndrome. AIDS is a serious condition that weakens the body's immune system, leaving it unable to fight off illness.

AIDS is the last stage in a progression of diseases resulting from a viral infection known as the Human Immunodeficiency Virus (HIV or AIDS virus). The disease include a number of unusual and severe infections, cancers, severe weight loss, diseases affecting the brain and central nervous system

The immune system is a network of cells, organs and proteins that work together to defend and protect the body from potentially harmful, infectious microorganisms. The immune system also plays a critical role in preventing the development and spread of many types of cancer.When the immune system is missing one or more of its components, the result is an immunodeficiency disorder AIDS.

Lymphocytes (white blood cells) are one of the main types of immune cells that make up the immune system. There are two types of lymphocytes: B cells and T cells. (T cells are also called CD4 cells, CD4 T cells, or CD4 cell lymphocytes). B cells release antibodies (proteins) into the body's fluids to attack antigens (foreign proteins such as bacteria, viruses or fungi). T cells directly attack and destroy infected or malignant cells in the body.

There are two types of T cells: helper T cells and killer T cells. Helper T cells recognize the antigen and activate the killer T cells. Killer T cells then destroy the antigen. When HIV is introduced into the body, this virus is too strong for the helper T cells and killerT cells. The virus then invades these cells and starts to reproduce itself, thereby not only killing the CD4 T cells, but also spreading to infect otherwise healthy cells. The HIV virus cannot be destroyed and lives in the body undetected for months or years before any sign of illness appears.

Gradually, over many years or even decades, as the T cells become progressively destroyed or inactivated, other viruses, parasites or cancer cells (called "opportunistic diseases") which would not have been able to get past a healthy body's defense, can multiply within the body without fear of destruction.

5.8.1 Life cycle of human immunodeficiency virus

1. HIV binds, fuses to immune system cells, releases its RNA.
2. HIV RNA converted to HIV DNA during reverse transcription.
3. Viral DNA enters host cell nucleus and is integrated into host cell chromosomal DNA.

4. HIV RNA is made and viral protease processes protein for viral assembly
5. Newly made HIV buds from the cell and is ready to infect other cells

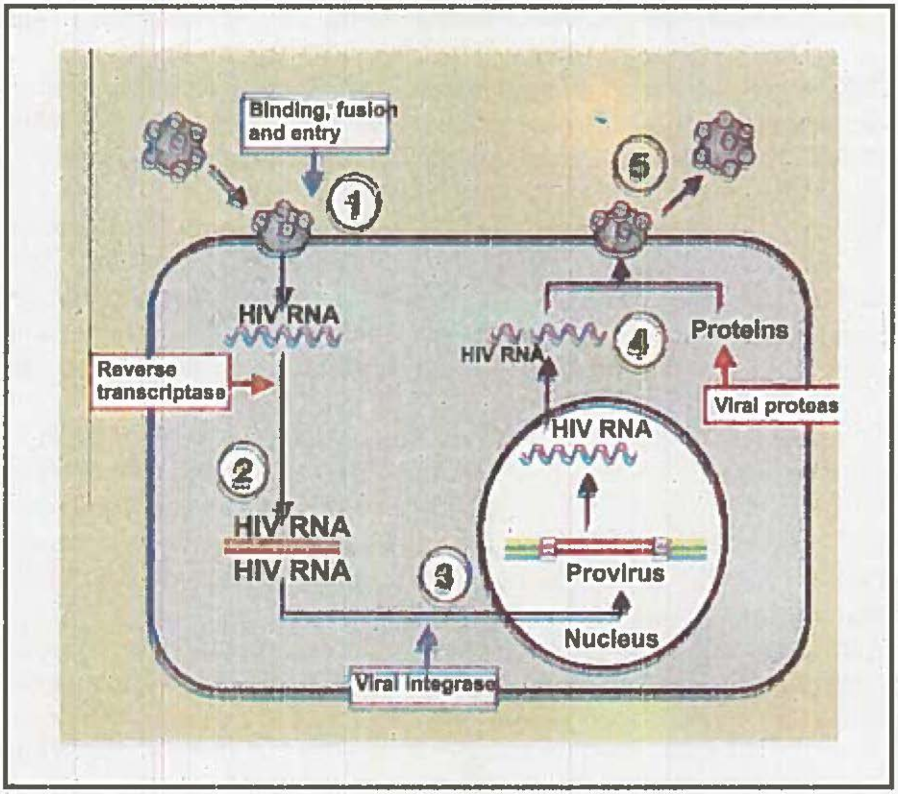


Fig 5.7 Life cycle of HIV

6. The HIV particles are then released or 'bud' from the cell. The enzyme protease plays a vital role at this stage of the HIV life cycle by chopping up long strands of protein into smaller pieces, which are used to construct mature viral cores.

The newly matured HIV particles are ready to infect another cell and begin the replication process all over again. In this way the virus quickly spreads through the human body. And once a person is infected, they can pass HIV on to others in their bodily fluids

5.8.2 Symptoms of HIV

The earliest symptoms include: fever, rash, muscles aches and swollen lymph nodes and glands. However, for most people, the first symptoms of HIV will not be apparent.

Although the infection is slowly taking hold of the body, the majority of those infected with HIV will be asymptomatic. Only by being **tested** for HIV one can know for sure if he/she has been infected.

Without **treatment**, people infected with HIV can expect to develop AIDS eight to ten years after HIV infection.

5.8.3 Opportunistic Invasions

Opportunistic infections are so named because they take advantage of weakened immune system. For example:

- Pulmonary tuberculosis
- Candidiasis of the esophagus, trachea, bronchi or lungs
- Toxoplasmosis of the brain
- Severe bacterial infections
- Recurrent pneumonia

Besides vision loss, nerve damage and brain impairment can also occur. Signs of brain deterioration include troubles thinking, loss of co-ordination and balance and behavioral changes.

5.8.4 Treatment for AIDS

There is no cure for HIV infection or AIDS nor is there a vaccine to prevent HIV infection. However, new medications not only can slow the progression of the infection, but can also markedly suppress the virus, thereby restoring the body's immune function and permitting many HIV-infected individuals to lead a normal, disease-free life.

Anti-HIV (also called antiretroviral) medications are used to control the reproduction of the virus and to slow or halt the progression of HIV-related disease. When used in combinations, these medications are termed Highly Active Antiretroviral Therapy (HAART). HAART combines three or more anti-HIV medications in a daily regimen, sometimes referred to as a "cocktail". Anti-HIV medications do not cure HIV infection and individuals taking these medications can still transmit HIV to others.

5.8.5 Prevention of AIDS and HIV Infection

AIDS is transmitted via these main routes:

- The most common mode of transmission is the transfer of body secretions through sexual contact. Blood or blood products can transmit the virus, most often through the sharing of contaminated syringes and needles.
- HIV can be spread during pregnancy from mother to fetus.
- Proper sterilization methods and disposable needles should be used for procedures, such as acupuncture, tattooing, ear piercing, etc.

- Screen blood for HIV should be given in case of blood transfusion. Anyone who thinks he or she is infected, or who is involved in high-risk behaviors, should not donate his/her blood, organs or tissues as they may now contain the AIDS virus
- Get professional help for terminating the drug habit.

5. 9 Some other Viral Diseases

a. Hepatitis

The word *hepatitis* means inflammation of the liver. Hepatitis is most commonly caused by one of three viruses:

1. **Hepatitis A** virus
2. **Hepatitis B** virus
3. **Hepatitis C** virus

1. Hepatitis A

In children, the most common form of hepatitis is hepatitis A (also called infectious hepatitis). This form is caused by the hepatitis A virus (HAV), which lives in the stools (feces or poop) of infected individuals. Because hepatitis A can be a mild infection, particularly in children, it's possible for some people to be unaware that they have had the illness. Although the hepatitis A virus can cause prolonged illness up to 6 months, it typically only causes short-lived illnesses and it does **not** cause chronic liver disease.

2. Hepatitis B

Hepatitis B (also called serum hepatitis) is caused by the hepatitis B virus (HBV). HBV can cause a wide spectrum of symptoms ranging from general malaise to chronic liver disease that can lead to liver cancer. HBV spreads through infected body fluids such as blood, saliva, vaginal fluid, tear and urine.

3. Hepatitis C

The hepatitis C virus (HCV) is spread by direct contact with an infected person's blood. The symptoms of the hepatitis C virus can be very similar to those of the hepatitis A and B viruses. However, infection with HCV can lead to chronic liver disease and is the leading reason for liver transplant. The hepatitis C virus can be spread by sharing drug needles, getting a tattoo or body piercing with unsterilized tools, blood transfusions, transmission from mother to newborn and sexual contact Hepatitis C is also a common threat in kidney dialysis centers. Rarely, people living with an infected person can contract the disease by sharing items that might contain that person's blood, such as razors or toothbrushes.

Diagnosis

All of these viral hepatitis conditions can be diagnosed and followed through the use of readily available blood tests.

Prevention

In general, to prevent viral hepatitis we should:

- Follow good hygiene and avoid crowded, unhealthy living conditions.
- Take extra care, particularly when drinking and swimming especially areas with poor sanitation and water quality.
- Wash hands thoroughly after using the toilet and before eating.
- Use antiseptic cleansers to clean toilet used by someone in the family who develops hepatitis.

For Your Information

For viral hepatitis, the incubation period (the time it takes for a person to become infected after being exposed) varies depending on which hepatitis virus causes the disease:

·For hepatitis A, the incubation period is 2 to 6 weeks.

·For hepatitis B, the incubation period is between 4 and 20 weeks.

·For hepatitis C, it's estimated that the incubation period is 2 to 26 weeks.

Coronaviruses (CoV) are a large family of viruses that cause illness ranging from the common cold to more severe diseases such as Middle East Respiratory Syndrome (MERS-CoV) and Severe Acute Respiratory Syndrome (SARS-CoV). A novel coronavirus (nCoV) is a new strain that has not been previously identified in humans. Most estimates of the incubation period for COVID-19 range from 1-14 days, most commonly around five days.

Treatment

When symptoms are severe or laboratory tests show liver damage, it's sometimes necessary for hepatitis to be treated in the hospital. Here's a quick look at the treatments available for the various hepatitis viruses: There are no medications used to treat hepatitis A because it's a short-term infection that goes away on its own.

Hepatitis B can sometimes be treated using medications. The treatment of hepatitis C has improved significantly with the use of two medications, only one of which is approved for use in children. In those adults who have just been infected with hepatitis C (by accidental needle injury, for example), combination therapy with the two drugs is the treatment of choice and can eliminate the virus in about 50% of the people infected.

b. Herpes

The herpes simplex virus, also known as HSV, is an infection that causes herpes. The herpes simplex virus is a contagious virus that can be transmitted from person to person through direct contact. There are two types of the herpes simplex virus.

- **HSV-1:** primarily causes oral herpes, and is generally responsible for cold sores and fever blisters around the mouth and on the face.
- **HSV-2:** primarily causes genital herpes, and is generally responsible for genital herpes outbreaks.

Symptoms

Herpes can appear in various parts of the body, most commonly on the genitals or mouth region.

Treatment

Doctor may prescribe an antiviral medicine in the form of an ointment or pills.

c. Polio

Poliomyelitis (polio) is a highly infectious viral disease, which mainly affects young children. It is caused by infection with the poliovirus. The virus spreads by direct person-to-person contact, by contact with infected mucus or phlegm from the nose or mouth, or by contact with infected feaces. The virus enters through the mouth and nose, multiplies in the throat and intestinal tract, and then is absorbed and spread through the blood and lymph system. The time from being infected with the virus to developing symptoms of disease, incubation ranges from 5 - 35 days (average 7 - 14 days).

Signs and Symptoms

Paralytic polio, as its name implies, causes muscle paralysis - and can even result in death. In paralytic polio, the virus leaves the intestinal tract and enters the bloodstream, attacking the nerves. In abortive or asymptomatic polio, the virus usually doesn't get past the intestinal tract. The virus may affect the nerves governing the muscles in the limbs and the muscles necessary for breathing, causing respiratory difficulty and paralysis of the arms and legs.

Treatment

The goal of treatment is to control symptoms while the infection runs its course.People with severe cases may need lifesaving measures, especially breathing help.Treatments include; antibiotics for urinary tract infections, medications (such as bethanechol) for urinary retention, moist heat (heating pads, warm towels) to reduce muscle pain and spasms, pain killers to reduce headache, muscle pain, and spasms (narcotics are not usually given because they increase the risk of breathing difficulty) and physical therapy, braces or corrective shoes, or orthopedic surgery to help recover muscle strength and function.

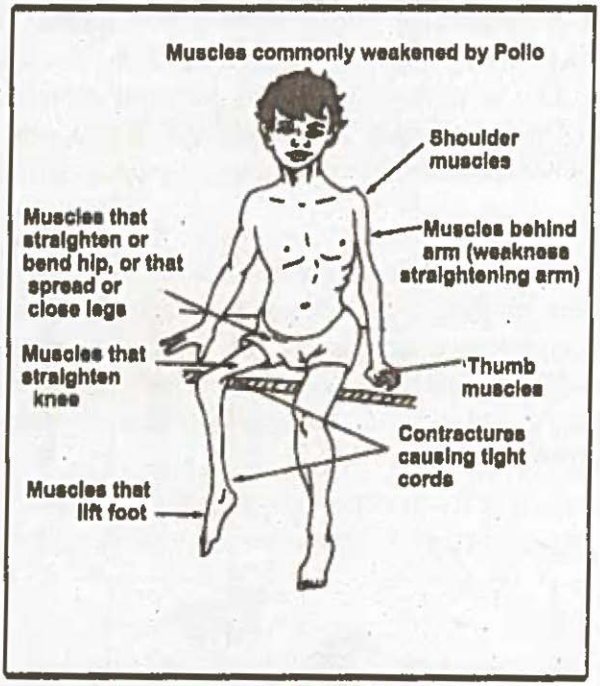


Fig: 5.8 Muscles are commonly weakened by Polio.

TIDBIT

The oral polio vaccine (OPV) administered to children during house-to-house polio campaigns in Pakistan is 100% safe, effective and is the essential tool available to protect all children against polio. It has no common side effects and has been used all over the world to protect children against polio virus.

Prevention

Polio immunization (vaccine) effectively prevents poliomyelitis in most people (immunization is over 90% effective).

d. Leaf curl disease of cotton

Cotton leaf curl disease is caused by a complex of begomovirus species, all of which incite similar symptoms in cotton and are transmitted by the whitefly *Bemisia tabaci.*

Symptoms

The first symptoms of infection in cotton appear within 2-3 weeks of inoculation and are initially characterised by deep downward cupping of the youngest leaves. This is followed by either upward or downward curling of the leaf margins and swelling, darkening and formation of enations on the veins, which frequently (depending on cultivar) develop into cup-shaped, leaf-like structures.

5.10 Prions

Prions are infectious protein particles thought to be responsible for a group of transmissible neurodegenerative diseases. Most evidence indicates that the infectious prion proteins are modified forms of normal proteins coded for by a host gene in the brain. It is thought that the normal prion protein, expressed on stem cells in the bone marrow and on cells that will become neurons, plays a role in the maturation of neurons.

In Scrapie the central nervous system of sheep and goats is affected. The transmission of scrapie is mainly due to the unhygienic way of feeding unhealthy or infected food.

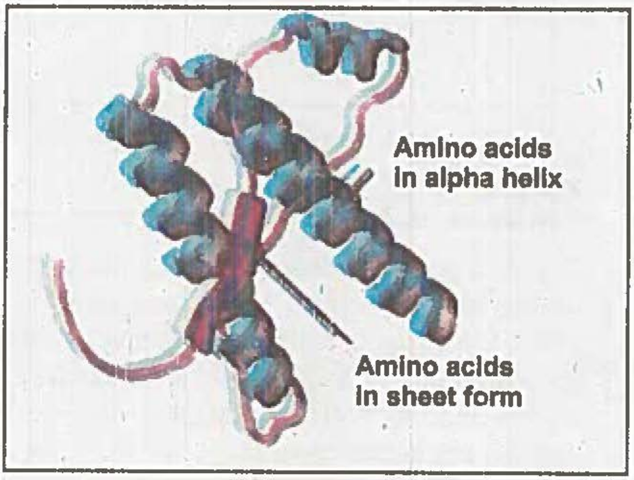


Fig: 5.9 Prion

Humans are susceptible to several prion diseases. Some of these are given below.

CJD: Creutzfeld-Jacob Disease

It is a fatal degenerative brain disorder. Early symptoms include memory problems, behavioral changes, poor coordination, and visual disturbances.

GSS: Gerstmann-Straussler-Scheinker

This disease is a rare genetic degenerative brain disorder. A common symptom is a progressive loss of coordination that may present as unsteadiness of gait, difficulty walking, dementia and clumsiness.

FFI: Fatal familial Insomnia

It is a very rare sleep disorder. It affects the thalamus and its main symptom is insomnia, speech problems and dementia.

Alpers Syndrome

Alpers syndrome is a neurological disorder. It Symptoms include increased muscle tone with exaggerated reflexes (spasticity), seizures , and dementia.

5.11 Viroids

Viroids are even more simple than viruses. They are small, circular, single-stranded molecules of infectious RNA lacking even a protein coat. They are the cause of a few plant diseases such as potato spindle-tuber disease,cucumber pale fruit, citrus exocortis disease, and cadang-cadang disease of coconuts.

The only human disease known to be caused by a viroid is hepatitis D. The first viroid discovered was the potato spindle tuber viroid (PSTV) I which causes a disease in potatoes. It has been reported that the infectious agent for the disease was not a conventional virus but free RNA. PSTV is a circular RNA molecule whose nucleotide sequence and secondary structure has been established.

TIDBIT

Virions range in size from approximately 20 nanometres (0.0000008 inch) to 250 nanometres and are of various shapes.

KEY POINTS

- Viruses are unique -- they have been classified as both living and nonliving at various points in the history of biology.
- A virus particle, also known as a virion, is essentially a nucleic acid (DNA or RNA) enclosed in a protein shell or coat.
- Viruses cannot reproduce or express their genes without the help of a host.
- Bacteriophage (phage) are obligate intracellular parasites that multiply inside bacteria by making use of the host biosynthetic machinery.
- All phages contain a head structure which is composed of many copies of one or more different proteins. Inside the head is found the nucleic acid (DNA or RNA).
- HIV belongs to a special class of viruses called retroviruses
- Influenza is an RNA virus. Hemagglutinin (HA) and neuraminidase (NA) are stuck onto the lipid envelope of the influenza virus and both play a crucial role in the infection of the epithelial cells of the upper respiratory tract.
- Viruses have evolved many ways of evading the immune system.
- Viral reproduction is most fully understood through studying viruses that infect bacteria, known as bacteriophages (or, commonly, phages). The lytic cycle and the lysogenic cycle are two fundamental reproductive processes that have been identified.
- The lytic cycle is a five-stage cycle which consists of attachment penetration, replication, assembly and lysis.
- Phages can be used as cloning vectors to introduce recombinant DNA into bacterial cells.
- AIDS is the last stage in a progression of diseases resulting from a viral infection known as the Human Immunodeficiency Virus
- The earliest symptoms of **HIV infection** occur when the body begins to form antibodies against the virus between six weeks and three months after infection with the HIV virus
- There is no cure for HIV infection or AIDS nor is there a vaccine to prevent HIV infection. However, new medications not only can slow the progression of the infection.

KEY POINTS

- The word *hepatitis* means inflammation of the liver.Hepatitis is most commonly caused by one of three viruses:the **hepatitis A** virus, the **hepatitis B** virus,the **hepatitis C** virus
- Genital herpes is a sexually transmitted disease (STD) that's usually caused by the herpes simplex virus type 2 (HSV2), although it can also be caused by herpes simplex virus type 1 (HSV1), which normally causes cold sores around the mouth.
- Poliomyelitis (polio) is a highly infectious viral disease, which mainly affects young children.
- Cotton leaf curl disease is caused by a complex of begomovirus species, all of which incite similar symptoms in cotton and are transmitted by the whitefly *Bemisia tabaci.*
- Prion proteins are modified forms of normal proteins coded for by a host gene in the brain.
- Viroids are small, circular, single-stranded molecules of infectious RNA lacking even a protein coat. They are the cause of a few plant diseases.

EXERCISE ?

A. Choose the correct answer in the following questions.

1. T-series bacteriophage can be recognized by its:
   a. irregular shape　　b. rounded shape
   c. tadpole shape　　d. rhomboidal shape
.2. The infective nature of virus is due to:
   a. protein coat　　b. nucleic acid
   c. envelope　　d. tail fibres
3. Which of the following is not associated with prions?
   a. Neurodegenerative disease　　b. Leaf curl disease
   c. Toxic proteins　　d. Alper's syndrome
4. Which statement is true of viroids?
   a. They are single-stranded RNA particles.
   b. They are single-stranded DNA particles
   c. They reproduce only outside of the cell.
   d. They belong to begomovirus.
5. Which one of the following enzymes is present in the bacteriophage?
   a. Succinic dehydrogenase　　b. Lysozyme
   c. Protease　　d. Urease
6. An infectious RNA particle without protein coat:
   a. viroid　　b. virion
   c. virusoid　　d. prion
7. Which body system is most directly concerned with vaccination?
   a. Digestive　　b. Circulatory
   c. Respiratory　　d. Immune
8. Tobacco mosaic virus is:
   a. spherical shaped　　b. cuboidal
   c. rod shaped　　d. oval shaped
9. Which one of the following is a disease caused by viroids?
   a. Creutzfeld-Jacob Disease　　b. Gerstmann-Straussler-Scheinker
   c. Fatal familial Insomnia　　d. cadang- cadang disease

B. Write short answers to the following questions.

1. Give a brief status of viruses in classification.

2 Differentiate between a retrovirus and a typical bacteriophage.

3. What are the consequences of a viral DNA becoming incorporated into a human egg or sperm cell?

4. How do viruses suppresses the immune system in human body?

5. Why do viruses need a host cell?

6. List down the main steps in the life cycle of HIV.

7. How lymphocytes maintain a healthy immune system in human body?

C. Write detailed answers to the following questions.

1. Explain how a virus manages to survive inside a host cell protected from the immune system?
2. Describe the role of bacteriophage in genetic engineering.
3. Describe some common control measures against the transmission of HIV.
4. Describe the causative agent, symptoms, treatment and prevention of leaf curl virus disease of cotton.
5. Write a brief note on prions and viroids.

Projects

- Collect information from the internet and make a report exhibiting the relationship of viral out break and linked to it the global economic losses with special reference to havoc created by corona virus at the dawn of 2020 A.D.
- Make a presentation explaining the correlating the social and cultural values of a country with the prevalence of AIDS.

Chapter 6

Prokaryotes

At the end of this chapter students will be able to:

- Outline the taxonomic position of prokaryotes in terms of domains archaea and bacteria and in terms of kingdom monera.
- Explain the phylogenetic position of prokaryotes.
- List the unifying archeal features that distinguish them from bacteria.
- Explain that most Archaea inhabit extreme environments.
- Justify the occurrence of bacteria in the widest range of habitats.
- List the diagnostic features of the major groups of bacteria.
- Justify why cyanobacteria are considered as the most prominent of the photosynthetic bacteria.
- Describe detailed structure and chemical composition of bacterial cell wall and other coverings.
- Compare cell wall differences in Gram-positive and Gram-negative bacteria.
- Explain the great diversity of shapes and sizes found in bacteria.
- Justify the endospore formation in bacteria to withstand unfavorable conditions.
- Explain motility in bacteria.
- Describe structure of bacterial flagellum.
- Describe genomic organization of bacteria.
- Classify bacteria on the basis of methods of obtaining energy and carbon.
- Describe autotrophic and heterotrophic nutrition in bacteria.
- Explain the pigment composition in cyanobacteria.

- Differentiate between the photosynthesis mechanisms in cyanobacteria and other photosynthetic bacteria.
- List the phases in the growth of bacteria.
- Describe different methods of reproduction in bacteria.
- Explain how mutations and genetic recombinations lend variability to bacterial reproduction.
- Describe bacteria as recyclers of nature.
- Outline the ecological and economic importance of bacteria.
- Explain the use of bacteria in research and technology.
- Describe important bacterial diseases in man e.g. cholera, typhoid, tuberculosis, and pneumonia; emphasizing their symptoms, causative bacteria, treatments, and preventative measures.
- Describe important bacterial diseases in plants in terms of spots, blights, soft rots, wilts, and galls; emphasizing their symptoms, causative bacteria, and preventative measures.
- Define the term normal flora.
- List the important bacteria that make the normal bacterial flora residing in the oral cavity, respiratory and urinogenital tracts and large intestine of man.
- Describe the benefits of the bacterial flora of humans.
- List the chemical and physical methods used to control harmful bacteria.

Introduction

Living world is divided into prokaryotes and eukaryotes. Prokaryotes are characterized by the absence of true nucleus and membrane-bound organelles. Prokaryotes are the simplest, most abundant and ancient organisms living on earth today. They closely resemble the first organisms to evolve on earth. They lived and evolved all alone on earth for over a billion years before the advent of eukaryotes. They had the ability to exploit the harsh conditions prevailing on planet earth.Prokaryotes are too small to be seen without a microscope. Life on earth cannot exist without prokaryotes because they are involved in many essential functions including fixation of atmospheric nitrogen, decomposition of organic matter and photosynthesis which is the source of much of the oxygen in earth atmosphere.

6.1 Taxonomy of Prokaryotes

In five kingdom system of classification of Whittaker, all prokaryotes are placed in kingdom monera, whereas eukaryotes are distributed in four other kingdoms viz, protista, plantae, fungi and animalia.

Prokaryotes cannot easily be classified simply on the basis of their forms. Sufficient information on their biochemical and metabolic characteristics has been gathered which helped in developing a satisfactory classification of prokaryotes. These characteristics are mode of nutrition, motility, form and method of division.

6.2 Phylogeny of Prokaryotes

It is a challenging job to study genetic diversity in prokaryotes due to their large number and difficulty to culture in laboratory. A new technique based on the use of polymerase chain reaction (PCR), has made it possible to study the genome of prokaryotes.

This has revealed that over hundreds of millions of years, prokaryotes acquired genes from distantly related species and they continue to do so even today. New information and research would accumulate and would lead to rise in certain new groups in prokaryoptes. About 6300 species of prokaryotes have been identified and many more will be identified in the days to come.

Prokaryotes in their early life on earth diverged into two main lines of ancestry i.e. archaea and bacteria. Little is known about the evolutionary history of archaea but it is believed that both groups have a common ancestor.

6.3 Archaea

Archaea are distinctive in several ways. Some of the major differences which

exist between archaea and bacteria are:

- The plasma membrane of both is made up of lipid bilayers but they contain different kinds of lipids.
- The cell wall in bacteria is made up of carbohydrates-protein complex called peptidoglycan but the cell wall of archaea lacks this complex.
- Archaea has a unique type of ribosomal RNA different from that of bacteria.

Archaea live in both extreme and moderate environments. Those inhabiting extreme condition are called extremophile (lovers of extreme environment) and the other group living in moderate conditions are known as methanogens. The extremophiles are further divided into extreme halophiles and extreme thermophiles. Extreme halophiles live in high-salt environments such as Utah's Great Salt Lake and Dead Sea. The proteins and cell walls of these archaea help to survive in saline conditions. These organisms cannot survive if the salinity drops below certain level. Extreme thermophiles thrive in very hot environments. Some of these organisms live in sulphur-rich volcanic springs as hot as 90°C where most other organisms do not survive because their DNA cannot maintain its double helical structure and many proteins denature at this temperature. Some extreme thermophiles are found forming dense communities in boiling water121°C above an active volcano 150 feet below the surface of Pacific Ocean at Macdonald Seamount.

Methanogens live in strict anaerobic environment. They obtain energy in a unique way by using CO_2 to oxidize hydrogen releasing methane as a waste product. They may be found living in marshes, lake bottoms and intestines of some animals and water thick ice layers in Greenland.

6.4 Bacteria

Bacteria are microscopic organism first seen by Van Leeuwenhoek. Very little was known about them until the work of Louis Pasteur and Robert Koch in the last half of the 19^{th} century. Bacteria occur in a wide range of habitats. They play many ecological roles because of their diverse physiology. Some survive in hot water springs where the water temperature may be as high as 90°C. Others live in Antarctica under a very thick layer of ice.

Tidbit

Bacteria are the most abundant organisms. There are more living bacteria in our mouth than the mammals living on earth.

6.4.1 Classification of bacteria

The classification of bacteria is based on the morphology, mode of nutrition, biochemical and genetic characteristics. Major groups of bacteria are:

1. Proteobacteria

This is a large group of Gram-negative bacteria and includes photoautotrophs, chemoautotrophs and heterotrophs. Some proteobacteria are aerobic while others are anaerobic. It is divided into five sub-groups.

a. Alpha-proteobacteria

Many species of this subgroup are associated with eukaryotic hosts such as symbiotic association of *Rhizobium* species with the roots of leguminous plants for the fixation of atmospheric nitrogen.

b. Beta-proteobacteria

It is a nutritionally diverse group. The bacteria are involved in nitrogen recycling oxidizing ammonium , producing nitrites as a waste product.

c. Gamma-proteobacteria

The group includes sulphur bacteria which obtain energy by oxidizing H_2S instead of water.

d. Delta-proteobacteria

This subgroup includes the slime-secreting myxobacteria. When the soil is dry or food is scarce, they aggregate into fruit bodies releasing resistant myxospores. The members of the subgroup may get attached to other bacteria.

e. Epsilon proteobacteria

Most species included in this sub-group are pathogenic and cause diseases in humans and animals.

2. Chlamydias

They are parasitic Gram-negative bacteria and cause some common diseases of humans.

3. Spirochetes

These helical heterotrophs move in spiral course through their environment by means of rotating internal filaments. Many are free-living but others are notorious parasites of human race.

4. Gram-positive bacteria

This group contains both solitary and colonial forms. Actinomycetes, which is a subgroup of Gram-positive bacteria cause tuberculosis and leprosy. Most actinomycetes are free-living and decompose the organic matter in soil. Species of Streptomyces are cultured as a source of many antibiotics including streptomycin.

Mycoplasma is the only genus of bacteria known to lack cell walls.

5. Cyanobacteria

It is speculated that the first cell evolved fed on organic matter in the environment. But the shortage of organic material seems to diverge the attention of these organisms towards getting the energy from inorganic sources. The evolution of pigment in the cells made it possible to capture energy from sunlight and to store it in chemical bonds. The oxygen-producing bacteria like cyanobacteria took up this task. Cyanobacteria play important role in the evolution of life as their photosynthetic activity gradually oxygenated the atmosphere and the oceans about two billion years ago.

It was the beginning of great transition that changed the conditions on earth permanently. The level of oxygen was raised from 1% to the current level of 21%. With the increase of oxygen, the amount of ozone also increased in the upper layers of the atmosphere. The thick layer of ozone acted as a screen protecting the proteins and nucleic acids from destruction by ultraviolet radiation from sun. It encouraged the other autotrophs to appear and survive on earth. Some members of this group like Nostoc are involved the fixation of atmospheric nitrogen.

6.4.2 Structure of bacteria

a. Capsule

Many species of bacteria possess a tight protective covering around the cell called capsule. It is a very sticky, gelatinous structure made up of polysaccharides and proteins. These bacteria are called capsulated bacteria. The capsule prevents dehydration of bacterial cell. A capsule which is less tightly bound to the cell is commonly called glycocalyx.

b. Cell wall

The cell wall protects the cell and also gives it a definite shape. It is made up of peptidoglycan which is a carbohydrate-protein complex. The wall is laid in many layers and it makes the cell wall rigid. Based on the variations in the chemical constituents of cell wall, Hans Christian Gram, a Danish physician, developed a staining technique in 1884. He divided bacteria in two groups i.e. Gram-positive and Gram-negative bacteria. Gram-positive bacteria which are stained blue-purple with crystal violet dye, possess thick walls of peptidoglycan; they retain the dye when the cells are washed with an organic solvent like alcohol.

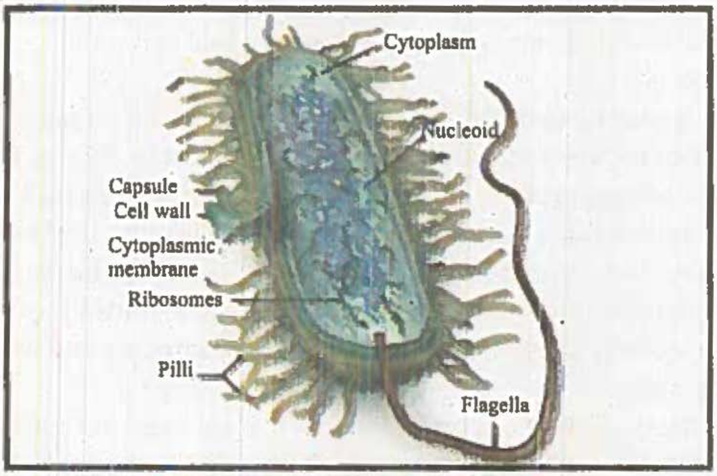


Fig: 6.1 Structure of Bacterial cell

Gram-negative bacteria have a thinner layer of peptidoglycan and lose the dye easily when rinsed with alcohol. Cell walls in Gram-negative bacteria are more complex; the thin peptidoglycan layer is covered externally by a layer of lipopolysaccharides. Gram-negative bacteria are more resistant than Gram-positive bacteria because the outer layer of lipopolysaccharides impedes the entry of antibiotics.

c. Flagella

Many species of bacteria possess thin hair-like appendages which help them in motility. Flagella are anchored in the cell wall and spin like a propeller, pulling the cell through water. A flagellum is composed of three parts i.e. a basal apparatus associated with the cytoplasmic membrane and cell wall; a short curved hook and a helical filament. The hook and the filament are made up of a protein called flagellin.

The flagella may vary in number and placement. A monotrichous bacterium possesses a single flagellum. A lophotrichous organism has a group of two or more flagella inserted at one pole of the cell. An amphitrichous bacterium is characterized by groups of flagella inserted at both end of the cell. In peritrichous bacterium flagella are dispersed on the entire surface of the cell. Some bacteria lack flagella and are called as atrichious.

d. Pilli

Pilli are small filamentous appendages scattered all over the surface of bacterial cell. They play no part in motility. Pilli are smaller than flagella in size. They are made up of protein called pillin. Pilli help the bacteria to attach to various surfaces but in some cases they are involved in the transfer of genetic material from one to another bacterium.

e. Cell membrane

Cell membrane lies inner to the cell wall. It is thin, delicate, flexible and selectively permeable. Chemically it resembles the membrane of eukaryotic cells with the exception that it contains different kinds of lipids. Cell membrane invaginates into cytoplasm to form pocket-like structure called mesosome. They help in cell division and replication of DNA.

f. Cytoplasm

Cytoplasm lies inside the cell membrane. It is a gelatinous mass of proteins, carbohydrates, lipids, nucleic acids, salts and inorganic ions dissolved in water. It is thick, semi-transparent and elastic and lacks membrane-bounded organelles,. The semi fluid jelly-like portion of cytoplasm enclosed by the cell membrane is called cytosol

g. Ribosomes

Ribosomes are RNA-protein bodies found freely dispersed within the cytoplasm. They are associated with the synthesis of proteins. They are smaller in size than the ribosomes of eukaryotic cells.

h. Genomic organization

The genome of bacteria is different from a eukaryotic genome and possesses less DNA. It consists of a single circular chromosome containing few-proteins than a linear chromosome of eukaryote. A membrane-bounded nucleus is missing here. The chromosome is located in a specific region of cytoplasm called nucleoid. In addition to its single circular chromosome, the cell also possesses extra chromosomal DNA rings of small size called plasmids. Plasmids carry a fewer genes than the normal bacterial chromosome and replicate separately independent of the normal chromosome.

6.4.3 Size and Shape of bacteria

Most bacteria are about 2 to 10 micrometer in length and 0.2 to 2 micrometer to in diameter. The shape of the bacterial cell is controlled by its rigid cell wall. They appear in three different forms.

a. Cocci (singular: coccus)

Cocci are spherical bacteria and are non-motile because they lack flagella. When these bacteria remain together in pairs after division, they are called diplococci. Those which form chains of diplococci are called streptococci.

b. Bacilli (singular: bacillus)

Bacilli are rod-shaped bacteria. Most rods occurs singly but some form pairs and are called diplobacilli, others forming chains are known as streptobacilli. *Salmonella typhi* causing typhoid and *Clostridium tetani* causing tetanus are bacilli bacteria.

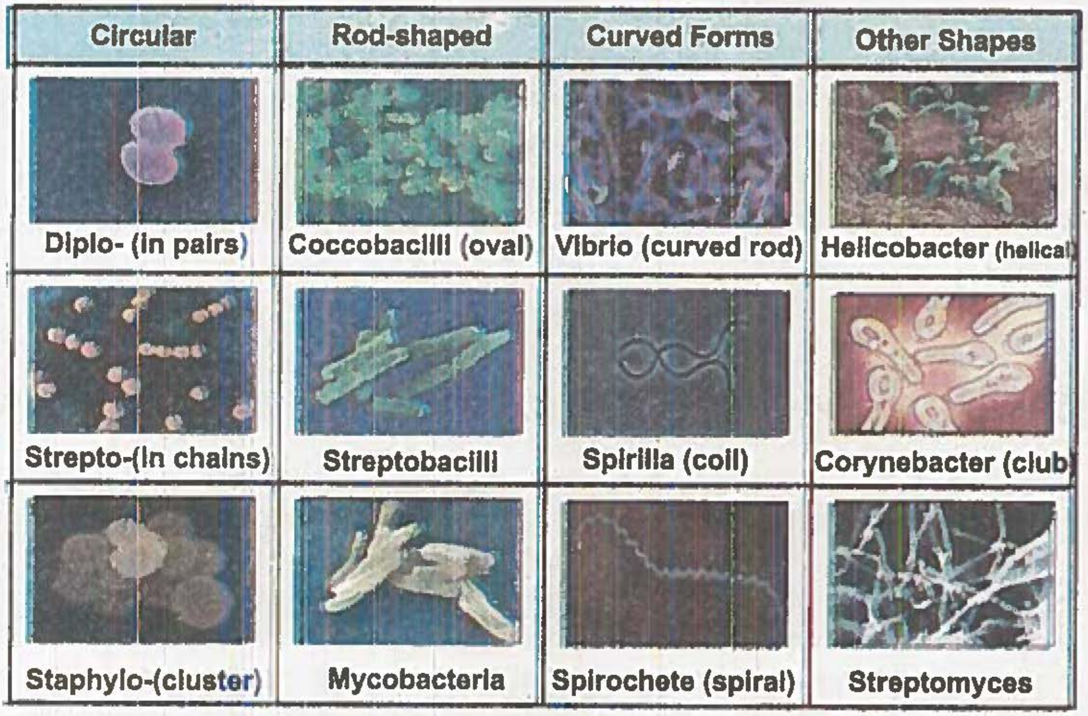


Fig: 6.2 Different shapes of bacteria

c. Spirilla (singular: spirillum)

They are corkscrew-shaped bacteria. They are motile and flagella are attached at the ends. Spirilla never form clusters or colonies. Some spirilla have less than one complete twist, look like commas and are called vibrios.

6.4.4 Endospores

Some Gram-positive bacteria produce highly resistant structures called endospores. The spores remain alive for many years under extremely harsh conditions with regarded to temperature, radiations and water shortage prevailing on earth in its early days.

Endospore may develop near the end or in the centre of the cell. It contains little water. The cell membrane grows in to seal off the developing spore. It is further protected by thick layers of peptidoglycan. When the external environment is favourable the protective layers break down and the spore is released which acts as a vegetative cell. Endospore formation is not a reproductive process as a vegetative cell forms a single endospore which later on produces one vegetative cell.

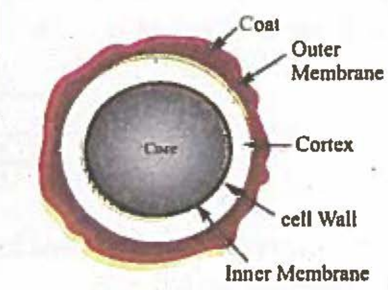


Fig: 6.3 Structure of Endospore

Tidbit

Live spores have been recovered from the intestines of Egyptian mummies. Archaeologists found the endopores alive from 7518 years old sediments of Minnesota's Elk Lake.

6.4.5 Mode of nutrition in bacteria

Bacteria, like other organisms, require food for growth and other vital activities. They need carbon and energy for their nutrition. Bacteria are divided into two groups on the basis of their nutritional approach i.e. autotrophs and heterotrophs.

a. Autotrophic bacteria

Autotrophic bacteria synthesize their food from simple carbon sources. They use inorganic carbon compound such as carbon dioxide and ions like carbonates, nitrates and sulphates. Energy needed for the synthesis of food comes from sun and chemical reactions occur in cytoplasm.

The autotrophic bacteria are further divided into two groups namely photoautotrophs and chemoautotrophs.

i. Photoautotophs

Photoautotrophic bacteria possess chlorophyll and can manufacture their food. The source of energy is sunlight which they capture through chlorophyll. The chlorophyll is not contained in chloroplasts but it dispersed in the infolded region of cell membrane in cytoplasm.

The source of hydrogen is hydrogen sulphide instead of water. Sulphur is released in the process instead of oxygen.

$$CO_2+H_2S \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} (C_6H_{12}O_6) + S$$

Some other photoautotrophic bacteria are purple sulphur bacteria, suluphur bacteria and non-sulphur bacteria.

ii. Chemoautotrophs

These bacteria do not use sunlight as a source of energy. They derive the energy by the oxidation of inorganic substances such as hydrogen sulphide, ammonia, nitrates, nitrites and iron compounds. Such a process of food formation is called chemosynthesis.

b. Heterotrophic bacteria

These bacteria are unable to prepare their own food. These organisms obtain energy from organic compounds prepared by other organisms. There are three types of heterotrophic bacteria i.e. saprophytic bacteria, parasitic bacteria and symbiotic bacteria.

I. Saprophytic bacteria

Saprophytic bacteria, commonly known as saprobes, feed exclusively on dead organic matter which is derived from plants and animals remains. These bacteria possess a powerful enzyme system which helps in the break down of complex organic compounds to simpler substance. They utilize the energy released in the process. The chemicals thus released become available to other organisms. The saprobes are called recyclers of nutrients. As they clean the earth by their action, they are also called the scavengers of earth.

ii. Parasitic bacteria

The parasitic bacteria do not possess the enzyme system for the breakdown of organic matter of their live hosts which include humans, plants and animals. Many parasitic bacteria cause diseases and are called pathogens.

iii. Symbiotic bacteria

"Symbiosis" means living together. Symbiotic bacteria develop a nutritional relationship with other organisms. The relationship may be beneficial to both partners and is called mutualism.

Another type of relationship is commensalism in which one partner is benefitted while the other is neither benefitted nor harmed. *Rhizobium radiciola* develops a symbiotic association with roots of leguminous plants. It forms nodules on the roots, fix atmospheric nitrogen and supply nitrogenous compounds to the plant and gets food and shelter in return from the plant.

6.4.6 Comparison of Photosynthesis in Bacteria and Cyanobacteria

The process of photosynthesis in photoautotrophic bacteria is different from cyanobacteria. In photosynthetic bacteria, oxygen is not released as by product whereas the cyanobacteria release oxygen during photosynthesis. The source of hydrogen in bacteria is hydrogen sulphide where as cyanobacteria, like plants, get hydrogen from water.

Photoautotroph bacteria have photosystem I but lack photosystem II. In bacteria cyclic electrons flow is the sole means of generating ATP and NADPH both. Bacteria possess bacteriochlorophyll "a" whereas the pigment complex in cyanobacteria consists of chlorophyll "a", phycocyanin, allophycocyanin and phycoerythrin.

6.4.7 Growth in Bacteria

In case of bacteria, growth means the increase in the total population rather than increase in the size of organism. Bacteria grow very fast and their growth is affected by temperature, availability of nutrients, pH and ionic concentration. Under favorable conditions, a bacterium divides after every 20 minutes.

The number of cells doubles at the end of each division. It is called exponential growth and the interval between two successive divisions is called generation time. It is different for different species of bacteria.

Phases of growth

In a typical growth curve of bacterium, four distinct phases of the curve are recognized. The lag phase covers the first few hours when there appears no growth. During this period, the bacteria become accustomed to their new environment.

Tidbit

The generation time for *Escherichia coli* is 20 minutes. If the division goes unchecked, after 36 hours there would be enough bacteria to cover the face of the earth.

The lag phase is followed by a period of fast growth called log phase. It represents an active stage of growth. The mass of cells increases and reproduction follows it. As each generation time passes, the number of bacteria doubles. In humans, the disease symptoms develop during the

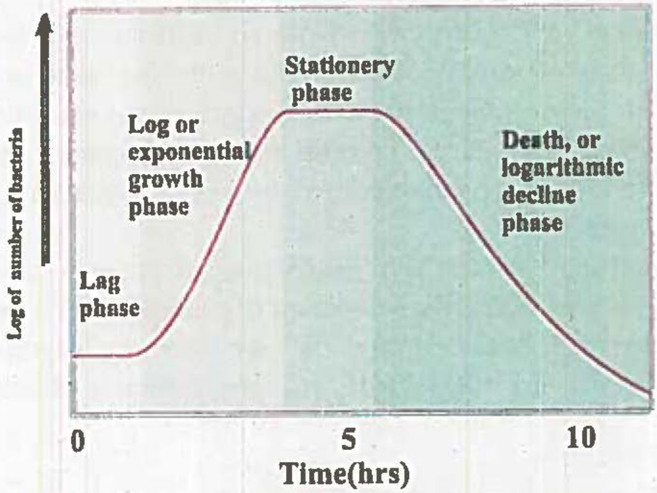


Fig: 6.4 Growth curve for bacterial population

log phase because the bacterial production attains such a high level which damages the tissues. Later on, the growth slows down because of the shortage of nutrients and is called as stationary phase. Later the number of dying cells exceeds the number of new cells formed. The population declines and it is called decline phase. The decline phase occurs because of the exhaustion of nutrients and the accumulation of toxic wastes.

6.4.8 Reproduction in bacteria

Most common method of reproduction in bacteria is asexual reproduction, but they can also reproduce sexually by genetic recombination which is primitive types of sexual reproduction.

a. Asexual reproduction

Asexual reproduction in bacteria takes place by binary fission. The cell and the cell membrane grows twice to its size, accumulates nutrients, chromosome replicates and the cell membrane grows inward at the middle of the cell. Usually a mesosome is attached to the cytoplasmic membrane at the location of inward growth. When the nuclear material is equally distributed, the cell wall thickens and grows inward to separate the dividing cell. In this type of division, no mitotic structure is formed.

Mutation and genetic recombination in bacteria

The genetic variation in bacteria is achieved either by mutation or genetic recombination. Mutation is a major source of variation in bacteria but additional diversity arises from genetic recombination. After a few round of binary fission, most of the offspring are genetically identical to the parent cell. The genetic diversity leads to fast evolution. Genetically better individuals survive and reproduce more prolifically than less fit individuals.

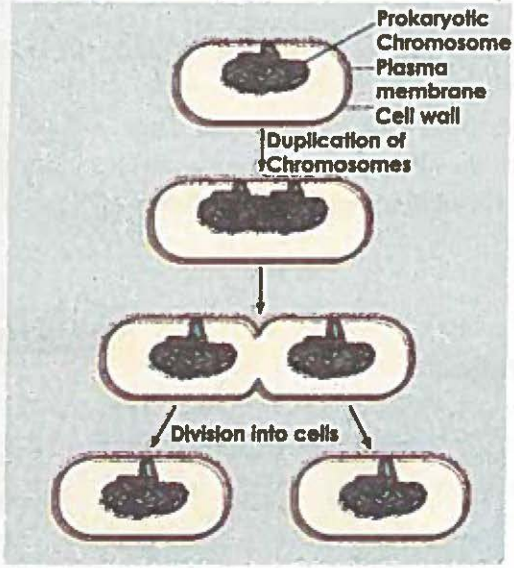


Fig: 6.5 Asexual reproduction in Bacteria

Mutation changes the bacterial chromosome by altering the DNA of the cell. In most cases, mutation involves a disruption of the nitrogen base sequence in DNA or the loss of a significant piece of chromosome.

In bacterial recombination the cells do not fuse and only a portion of DNA from the donor cell is transferred to the recipient cell. A fragment of the recipient DNA is replaced by donor DNA.

b. Sexual reproduction

In bacteria, sexual reproduction occurs by genetic recombination which is a primitive type of sexual reproduction. In genetic recombination, DNA from two different sources combine. The cells do not fuse, only a piece of DNA of donor cell is inserted in the recipient cell. In recipient cell, the DNA portion of the donor cell orients itself in such a way that the homologous genes come close to one another. A fragment of the DNA of the recipient is knocked off and DNA of donor is integrated into it. The recipient cell is now called a recombinant cell. There are three methods of bacterial recombination i.e transformation, transduction and conjugation.

i. Transformation

Streptococcus pneumonia has two strains, one causes pneumonia but the other is unable to do so. The cells of the virulent strain are capsulated from smooth colonies and are called S-types. The non-virulent strain is non-capsulated, forms rough colonies and is called R-type.

In 1928 Fredrich Griffith, an German microbiologist, injected live R-type cell into the body of a healthy mouse, the mouse remained alive and showed no symptoms of pneumonia. Then S-type live cells were injected into the body of another mouse, the mouse suffered from pneumonia and died. Heat-killed S-type cells were injected into the body of a healthy mouse, the mouse remained alive.

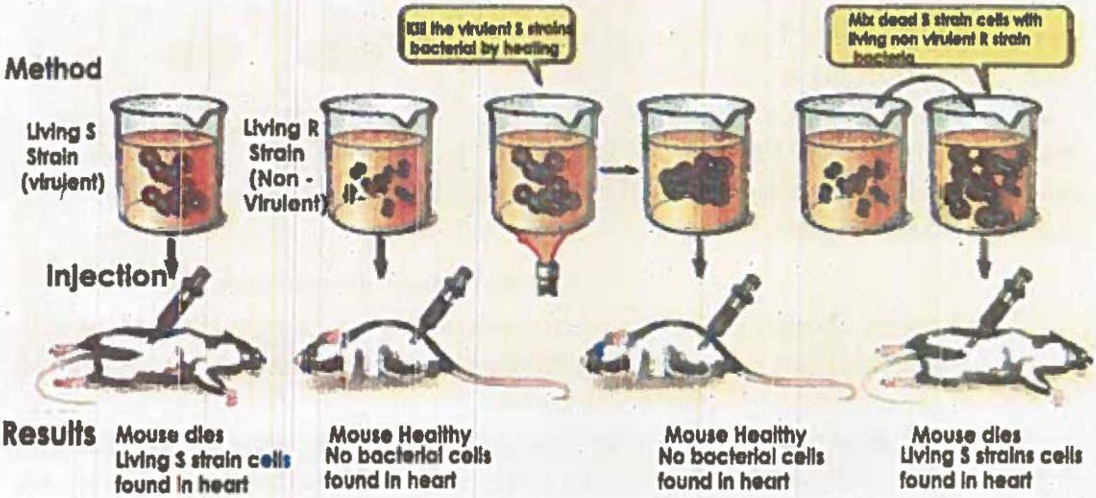


Fig: 6.6 Experiment showing transformation principle in bacteria

These results were all according to the expectations of the researchers. But what happened next puzzled Griffth and his associates. A mixture of heat killed S - type and live R-type was injected into the body of a healthy mouse, the mouse died from pneumonia. The autopsy revealed the presence of many living S-type cells in the dead body of the mouse. He concluded that the head-killed S-type cells released some substances which changed some of the R-type non-virulent cells into S-type virulent cells. The live R-type non-virulent bacteria were transformed into live S-type virulent bacteria.

Later Avery and his co-worker in 1944 isolated and identified the transforming substance as DNA. It is now known that during transforming a small fragment of DNA is released by donor bacteria and it is taken by the recipient where it replaces a similar piece of DNA.

ii. Transduction

Bacterial recombination by transduction was first reported by Lederberg and Zinder in 1952. A piece of DNA is transmitted from a donor cell to a recipient cell through a third party called bacteriophage. The phage attaches itself to the surface of the bacterial cell called donor bacterium and injects its DNA into the cell. The viral DNA directs the formation of protein coats. Sometimes a piece of DNA of donor bacterium may become attached to the DNA of phage, the recombinant DNA is known as prophage. Many phages are assembled in the bacterial cell which bursts and a crop of phages is released completing a lytic cycle. Phages which cause lysis are called virulent phages.

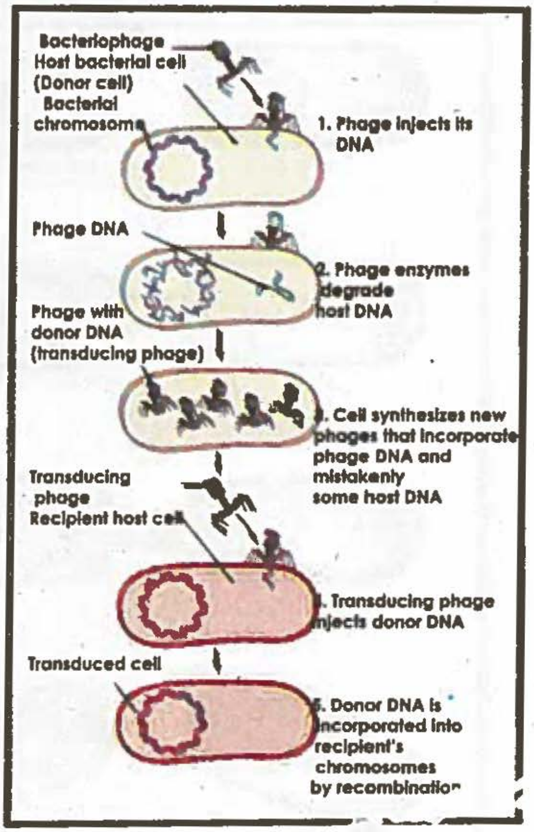


Fig: 6.7 Transduction in bacteria

Newly formed phage now attacks a new bacterium, inserts its DNA into the bacterium which is now called recipient bacterium. The lysogenic life cycle starts. The phage is called temperate phage. The recipient bacterium at this stage contains three types of DNA i.e DNA of its own, DNA of donor bacterium and DNA of phage. Now recipient cell's chromosome becomes a combination of DNA derived from both the bacterial cells i.e the recipient and the donor cells. With the division of recipient bacterium . all three types of DNA also replicate. In some daughter bacteria, some genes of donor DNA also express themselves donor and recipient bacteria. In this way, the genetic material of donor bacterium is carried to the recipient through a bacteriophage completing the process of transduction.

ii. Conjugation

Conjugation is a recombination process in which living bacteria come into direct contact and the donor cell transfers DNA to the recipient cell. The DNA transfer is one way. The process was studied in 1946 by Lederberg and Tatum in ***Escherichia coli.***

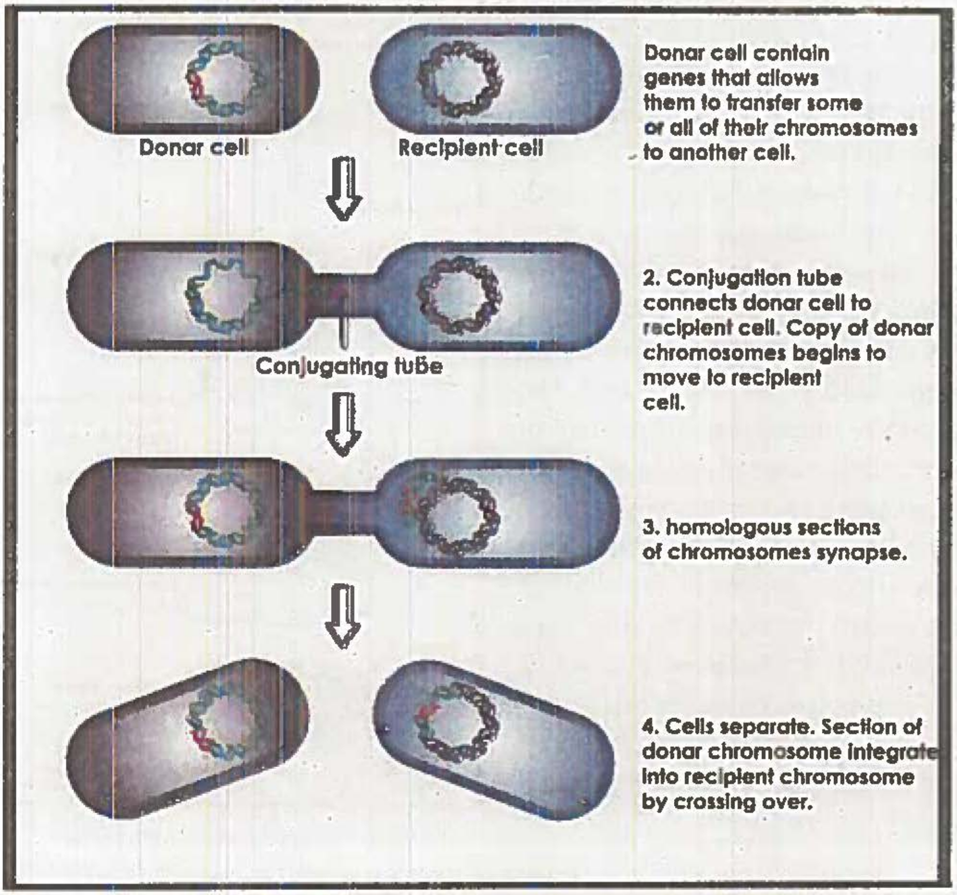


Fig: 6.8 Bacterial conjugation and recombination

Normally *Escherichia coli* can synthesize all amino acids it requires. It was exposed to shortwave radiation and two mutants were isolated. One mutant was unable to synthesize biotin (a vitamin) and amino acid methionine. The other mutant could not synthesize amino acids theronine and leucine. The four chemicals are essential for the growth of bacteria. The two mutants were mixed and cultured in a common medium lacking in all the four compounds. None of the cells would have grown in the absence of essential chemicals, but to the great astonishment of researchers, hundreds of colonies of bacteria developed. This suggests that exchange of genes has occurred between two parental bacteria and new recombinants were formed which did not require the four essential compounds for growth. Later studies made by electron microscope confirmed the close contact and the formation of conjugation tube between the parental cells.

6.5 Importance of Bacteria

i. In research technology

Bacteria are used in biotechnology. For example, *Escherichia coli* are used in gene cloning. *Agrobacterium tumefaciens* is used in producing transgenic plants such as Golden Rice which prevents blindness. Golden Rice contains beta-carotene, a precursor of vitamin A needed for normal vision. Bacteria are modified by genetic engineering to produce vitamins, antibiotics, hormones and other products. Humulin, human insulin is produced by using recombinant DNA technology. It also helps in producing disease resistant crop plants.

ii. As nutrient recyclers

Saprophytic bacteria are decomposers. They break down organic compounds like proteins and carbohydrates into simpler compound like CO_2 which is released in the atmosphere for recycling. It is fixed by green plants in photosynthesis. Other nutrients released in the process enter the soil and become available to plants. Bacteria can decompose the dead remains of plants and animals. Because of their cleaning action they are called the scavengers of planet earth. In sewage treatment, the bacteria bring about the break down of organic compounds and convert them into harmless ions such as nitrates and sulphates.

iii. Role in Ecology

Bacteria play important role in ecological interactions. They are involved in symbiotic nitrogen fixation in the roots of leguminous plants. Herbivorous mammals cannot break down cellulose. Bacteria live in their guts and help in the digestion of cellulose by breaking it down. The relationship is called commensalisms. Soil bacteria decompose the organic matter and make the soil fertile. Bacteria also play important role in nitrogen, phosphorus, sulphur and carbon cycles.

iv. Other uses of bacteria

Bacteria are used in the preparation of diary products such as butter, cheese and yoghurt. They are involved in the preparation of antibiotics, vinegar, amino acids and proteins. Bacteria are employed in retting of fibers and making of silage.

v. Spoilage of food

Bacteria spoil the food items. Foods with high protein contents are decomposed by bacteria. Eggs, fish and cooked food and milk are all spoiled by bacterial action.

6.6 Bacterial Diseases in Humans

A relatively small number of bacteria are the cause of many serious diseases of human beings. These diseases are transmitted through air, water, food and through wounds or cracks in the skin. Some of the diseases caused by the bacteria are discussed below.

1. Cholera

Cholera is caused by *Vibrio cholera*, a curved Gram-negative bacterium. It enters the intestinal tract from contaminated water and food. Bacteria secrete a toxin that stimulates the loss of fluid. Massive diarrhea is associated with cholera. Antibiotic such as tetracycline may be used to kill bacteria. In severely dehydrated cases oral rehydrated solution (ORS) is given to restore the normal balance of water and salts. The most important preventive measures include sanitation, personal hygiene and care in food preparation. Immunization against the disease gives protection for about six months.

2. Typhoid fever

Typhoid is caused by a rod-shaped Gram-negative bacterium called *Salmonella typhi*. This bacterium causes disease only in humans and is transmitted by **five Fs**, flies, food, fingers, feces and fomites(an object or substance that serves to transfer infectious organisms from one individual to another).

The symptoms of the disease are ulcers and blood in stools. The patient experiences mounting fever and lethargy. The treatment of typhoid fever is generally successful with antibiotics. Vaccines are available for immunization. Widal and typhidot test is used for diagnosis.

3. Tuberculosis (TB)

Tuberculosis is caused by *Mycobacterium tuberculosis*. It is a contagious disease. Poor quality of life and overcrowding increase the chances of occurrence of tuberculosis. The patient experience chronic cough, chest pain and high fever and expel sputum containing blood. A hard nodule called tubercle is formed in the lungs. The tubercle expands and the lungs slowly deteriorate. Patient must complete full course of medication to control and not allowing bacteria to develop. Immunization to tuberculosis is done by injecting the vaccine called Bacille Calmette Guerin (BCG).

4. Pneumonia

Pneumonia refers to a microbial disease of bronchial tubes and lungs. It is caused by bacteria, viruses and fungi. Over 80 percent of bacterial cases are due to *Streptococcus pneumoniae*. The patient with pneumonia experience high fever, sharp chest pains, difficulty in breathing and rust- coloured sputum. The blood seeps into the alveolar sacs of the lungs and the lung tissues gradually deteriorate. The drug given to pneumonia patient is penicillin with tetracycline and chloramphenicol used for people who are allergic to penicillin.

6.7 Some important bacterial diseases of plants

1. Bacterial leaf spots

This disease is caused by *Pseudomonas* spp. and *Xanthomonas* spp. Its host includes *Chrysanthemum, Delphinium, Heuchera, Hypericum* etc. Disease symptoms include water-soaked lesions on foliage that darken with age. Lesions may be bordered by the leaf venation. Bacteria on the plant surface are easily spread to nearby plants by splashing water from rain and irrigation. Most fungicides are not effective against bacteria. Copper-based products are helpful in limiting populations of surface-borne populations of bacterial pathogens.

Fig: 6.9 Bacterial Leaf spots

2. Bacterial wilt

Bacterial wilt (BW) is yet another plant disease caused by *Ralstonia solanacearum* that affects pepper, tomato and eggplant. At the early stages of disease, the first visible symptoms of bacterial wilt are usually seen on the foliage of plants. These symptoms consist of wilting of the youngest leaves at the ends of the branches.

Another common symptom that can be associated with bacterial wilt in the field is stunting of plants. Preventive measures of disease are: destroying the infected plants immediately, crop rotation, control of nematodes and use of disinfected farm tools.

Fig: 6.10 Bacterial wilt

3. Bacterial soft rot

Bacterial soft rots damage succulent plant parts such as fruits, tubers, stems and bulbs of plants in nearly every plant family. Soft rot bacteria degrade pectate molecules that bind plant cells together, causing plant structure to eventually fall apart. Woody tissues are not susceptible. Soft rots commonly affect vegetables such as potato, carrot, tomato, cucurbits (e.g., cucumbers, melons, squash, pumpkins), and cruciferous crops (e.g., cabbage, cauliflower)

Soft rots are caused by several bacteria, most commonly *Pectobacterium carotovorum* (previously called *Erwinia carotovora*), *Dickeya dadantii (previously called Erwinia chrysanthemi*), and certain species of *Pseudomonas*, *Bacillus* and *Clostridium.*

Fig: 6.11 Bacterial soft rot

Fig: 6.12 Bacterial gall

4. Bacterial galls

Crown gall is caused by a soil-inhabiting bacterium, *Agrobacterium tumefaciens*, which occurs worldwide and attacks over 600 plant species in more than 90 plant families. The most obvious symptoms are the galls or growths that usually occur on the twigs, stems, and roots near the base of the plant at the soil line. Gall size can vary from small to large and are usually spongy when young, but then become hard and woody with age.

5. Bacterial blights

Bacterial blights on different plants are known by different names and are caused by different species of bacteria. For example, bacterial blight of bean is caused by *Xanthomonas axonopodis pv. Phaseoli,* bacterial blight of cotton is caused by *X. axonopodis pv. Malvacearum,* Bacterial leaf blight of rice is caused by *X. oryzae pv. Oryzae etc.* it effects the plant through out its growth and leaves, pods, and fruits are affected in the process.

Fig: 6.13 Bacterial blights

Major preventive control of the disease includes crop rotation, use of diseased-free seeds, Insect pest control as they may serve as the carrier of the bacteria.

6.8 Bacterial Flora of Humans

The assemblage of microorganisms that constantly and consistently inhabit the human body is called human flora. They include bacteria, fungi and other organisms. Some of these organisms are known to perform tasks that are useful for the human body, while most of them produce no known beneficial or harmful effects. The microorganisms which are expected to be present and under normal circumstances do not cause disease are considered as member of the normal flora.

6.8.1 Benefits of normal Bacterial flora

1. Normal flora synthesizes and excretes vitamins in excess of their own needs. These vitamins are absorbed as nutrients by the human body.
2. It prevents colonization of pathogens by competing for attachment sites or for essential nutrients. In this way the normal flora of the human organs inhibits the growth of pathogenic bacteria through competitive exclusion. This is thought to be the most important beneficial effect of normal bacterial flora.
3. Normal flora of bacteria may antagonize other bacteria through production of substances which inhibit or kill non-indigenous bacteria. The intestinal bacteria produce many substances which inhibit or kill other bacteria.
4. Normal flora stimulates the production of natural antibodies inducting immunological response. Such antibodies are lacking in germ-free individuals.

Table: 6.1 Bacterial flora of humans

Body Part		Human flora
1.	Oral cavity	*Streptococci and lactobacilli.*
2.	Respiratory tract	*Streptococci, corynebacteria, Neisseria sp., Gramnegative rod and cocci.*
3.	Urinogenital tract	*Streptococci, corynebacteria and lactobacilli.*
4.	Large intestine	*Helicobacter sp., Bifidobacteria, Bacteroides sp.,* Lactic acid bacteria, *Clostridia and Methanogens.*

6.9 Control of Harmful Bacteria

Although the disease producing nature of bacteria become known 100 years after their discovery largely because of the research of Louis Pasteur and Robert Koch, however the early civilization used some crude techniques such as salting, smoking, picking, drying and exposure of food and clothing to sunlight to control microbial growth. Today microbial growth is controlled by physical and chemical methods.

a. Physical method

I. Heat treatment

Heat kills the microbes by denaturing their enzymes and other proteins. Autoclave chambers used for sterilization of surgical instruments.

Pasteurization is a process to prevent the spoilage of beverages such as juices, milk etc. A more effective method of pasteurization of milk is through ultra high temperature (UHT) in which milk is treated at 140°C for 3 seconds and then cooled suddenly in a vacuum chamber. Milk treated by UHT can be stored at room temperature for several months.

Incineration is dry heat treatment of sterilization of disposable items such as paper cups, dressing etc. the contaminated items are placed in an oven at 170°C for 2 hours to kill microbes.

ii. Filtration

Filtration is the removal of microbes by passage of a liquid or gas through a screen like material with pores. It is \used to sterilize heat sensitive material like vaccines, enzymes, antibiotics etc.

iii. Low temperature treatment

Refrigeration at temperature 0°C to 7°C reduces activities of microbes; they cannot reproduce or produce toxins. It is called bacteriostatic effect.

iv. Desiccation

Water is extracted from the contaminated material. In the absence of water, bacteria cannot grow or reproduce.

v. Osmotic pressure treatment

The high concentration of salt or sugar in food increase its osmotic pressure and creates a hypertonic environment which helps in controlling the growth of microbes.

vi. Radiation

Three types of radiation i.e ionizing radiation, ultraviolet light and microwave radiation are used to kill microbes.

b. Chemical Methods

Different groups of chemicals are used for disinfecting various products.

i. Phenolics are effectively used against Gram-positive bacteria in nurseries but their excessive use in infants is harmful.

ii. Among halogens, chlorine is used to disinfect drinking water and pools. Tincture iodine is one of many antiseptics used.

iii. Formaldehyde (formalin) is widely used to preserve biological specimens. It inactivates bacteria in vaccines. Glutaraldehyde is less irritating but more effective than formalin. It is used to disinfect hospital instrument.

iv. Ethylene oxide kills all microbes and endospores but requires 4-18 hours exposure.

KEY POINTS

- Prokaryotes cannot easily be classified simply on the basis of their forms. Sufficient information on their biochemical and metabolic characteristics has been gathered which helped in developing a satisfactory classification of prokaryotes.
- Archaea are distinctive in several ways and are closely related to eukaryotes as they are true bacteria.
- Archaea live in extreme and moderate environments both; those inhabiting extreme condition are called extremophile (lovers of extreme environment) and the other group living in moderate conditions are known as methanogens.
- Bacteria are the most abundant organisms.The classification of bacteria is based on the morphology, mode of nutrition, biochemical and genetic characteristics.
- Major groups of bacteria are: Proteobacteria, Chlamydias, Spirochetes, Gram-positive bacteria, Cyanobacteria.
- There are three methods of bacterial recombination i.e transformation, transduction and conjugation.
- A relatively small number of bacteria are the cause of many serious diseases of human beings. These diseases are transmitted through air, water and food.

EXERCISE ?

A. Choose the correct answer for the following questions.

1. The first forms of life on Earth were thought to be:
   a. protista b. prokaryotes
   c. insects d. dinosaurs

2. Dead sea are home to which of the following groups of organisms?
   a. Halophiles b. Thermophiles
   c. Halophytes d. Phytoplanktons

3. *Rhizobium* belongs to which of the following subgroup of proteobacteria?
   a. Alpha- proteobacteria b. Delta-proteobacteria
   c. Gamma- proteobacteria d. Epsilon proteobacteria

4. The first organisms that oxygenated the atmosphere were:
   a. cyanobacteria b. phototrophic organisms
   c. anaerobic organisms d. saprophytes

5. One of the feature of prokaryotic genome which makes it different from the eukaryotic genome is :
   a. it is made up of DNA only
   b. it is made up of RNA only
   c. it is made up of larger ribosome
   d. it is made up of smaller ribosomes

6. Organisms most likely to be found in extreme environments are:
   a. fungi b. algae
   c. viruses d. archaea

7. Peptidoglycan is a characteristic of the walls of :
   a. eukaryotic cells b. bacterial prokaryotic cells
   c. archaean prokaryotic cells d. bacterial and archaean prokaryotic cells.

8. The lipopolysaccharide layer (LPS) is a characteristic of the wall of :
   a. archaean cells b. Gram-negative bacteria
   c. bacterial prokaryotic cells d. eukaryotic cells

EXERCISE ?

9. An extra-chromosomal DNA ring in bacteria is called
   a. Nucleoid b. Plasmid
   c. Pili d. Mesosome

10. In photoautotrophic bacteria the source of hydrogen in photosynthesis is
   a. H_2O b. H_2S
   c. H_2O_2 d. H_2SO_4

11. In bacteria fastest growth occurs in the phase called
   a. Log phase b. Lag phase
   c. Stationary phase d. Decline.phase

10. The reproduction in which the genetic material is transmitted from a donor to a recipient bacterium through a phage is called
   a. Transformation b. Conjugation
   c. Binary fission d. Transduction

B. `Write short answers of the following questions.

1. Why has monera become obsolete?
2. What is a domain? Why is this term coined?
3. What is the role of prokaryotes in supporting life on earth?
4. What are main differences between archaea and bacteria?
5. What are plasmids and what are their importance?
6. What is the function of endospores?
7. What do you mean by genetic recombination?
8. Why are the bacteria called nutrient recyclers?
9. Discuss the role of radiation in controlling bacterial growth.

C. Write answers of the following questions.

1. Give an account of the structure of a bacterium.
2. Discuss various methods of sexual reproduction of a bacteria.
3. Describe the mode of nutrition in bacteria.
4. Give an account of bacterial diseases of plants.
5. Describe the normal flora of some important organs of humans and also discuss its benefits

EXERCISE ?

6. Describe the symptoms, causative bacteria, treatment and preventive measures of tuberculosis.
7. Write an essay on the importance of bacteria.

Projects:

- Arrange a general survey to the different famous food spots of your area and make a comprehensive report related to prevalent causes of food poisoning and the general sanitation conditions in these spots.
- Working in group of four, explore how bacterial diseases have affected human societies in the past. Gather information from different sources to explore how epidemics have been controlled by adopting different measures. Share your findings in power point presentation/on charts with your class fellows.
- In the recent time biotechnology has opened new avenues for manipulating bacteria in the preparation of different useful products. Make a list of five useful products prepared and used as drugs currently.

Chapter 7

Protista and Fungi

At the end of this chapter the students will be able to:

- Explain protists as a diverse group of eukaryotes that has polyphyletic origin and defined only by exclusion from other groups.
- Describe the salient features with examples of protozoa, algae, myxomycota and oomycota as the major groups of protists.
- Justify how protists are important for humans.
- List the characteristics that distinguish fungi from other groups and give reasons why fungi are classified in a separate kingdom.
- Classify fungi into zygomycota, ascomycota and basidiomycota and give the diagnostic features of each group.
- Explain yeast as unicellular fungi that are used for baking and brewing and are also becoming very important for genetic research.
- Name a few fungi from which antibiotics are obtained.
- Explain the mutualism established in mycorrhizae and lichen associations.
- Give examples of edible fungi.
- Describe the ecological impact of fungi causing decomposition and recycling of materials.
- Explain the pathogenic role of fungi.

Introduction

Protists are the simplest eukaryotes.. Protists are not animals, plants, or fungi. The protist kingdom is sometimes called the "trash can" kingdom. It includes all eukaryotes that don't fit in one of the other three eukaryote kingdoms: Animalia, Plantae, or Fungi. The protist kingdom is very diverse. There are thought to be between 60,000 and 200,000 protist species. Many have yet to be identified. Protists range from single-celled amoebas to multicellular seaweed. Protists may be similar to animals, plants, or fungi. Scientists think that protists are the oldest eukaryotes. If so, they must have evolved from prokaryotic cells. Fungi include some of the most important organisms, both in terms of their ecological and economic roles. By breaking down dead organic material, they continue the cycle of nutrients through ecosystems. In this chapter you will study a brief over view of the kingdom Protista and Kingdom fungi.

7.1 Protista

Most of the protists are unicellular but some are multi-cellular or colonial. Many have mitochondria although some never possessed any while some have later lost them. It is thought that ancestral prokaryotic cells, which then became mitochondria in the eukaryotic cells. The process is called **endosymbiosis.** Many protists possess chloroplast for photosynthesis. Chloroplast may also have originated this way with eukaryotic cells engulfing photosynthetic bacteria. The common ancestry of protista seems doubtful. The group of organisms has long independent evolutionary history stretching as far back as two million years. They seem to have a polyphyletic origin. Some groups are probably placed together more for convenience than as a reflection of close kinship. But the genome analysis, added to other criteria, enables us to postulate some groupings.

Protista can be categorized into three main groups:

a. Animal like Protists (Protozoa)

b. Plant like Protists

c. Fungi like Protists

a. Animal like Protists (Protozoa)

These organisms are called protozoans and they share some common traits with animals. All animal-like protists are heterotrophs and are motile. Animal-like protists are unicellular and they are divided into four basic groups based on how they move and live. Some are also parasites that can cause diseases. The Protozoa is often divided into 4 groups which are discussed below.

1. Zooflagellates or kinetoplastids

These protists move by using their whip-like flagella. Many of these protists live in the bodies of other organisms. They could harm their host by having a parasitic relationship or at other times they are mutualistic with their host. Trypanosomes is a parasite which is a cause of many serious human diseases. The most familiar being trypanosomiasis, also known as African sleeping diseases.

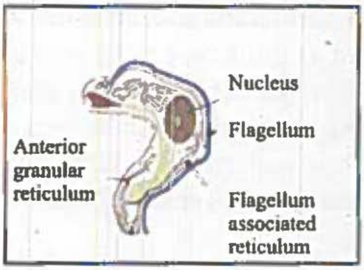


Fig: 7.1 Structure of *Trypanosomes* Fig: 7.2 Termites feed upon wood

One of the example of mutualistic relationship in this group is between termites and trichonymph. Termites feed upon wood but they cannot digest it due to the absence of a specific enzyme which brings about the breakdown to digest the wood eaten by termite. Trichonymph lives in the digestive tract of termites and produce an enzyme that helps in the digestion of wood.

2. Amoeboid protozoan or sarcodines

Their organ of locomotion are pseudopodia which are temporary protoplasmic outgrowths. These are also used for engulfing food articles. Sarcodines are mostly free-living, found in fresh water, sea water and on damp soil. One of the familiar example is amoeba. It is soft, shapeless masses of cytoplasm. The change in shape is brought about by cytoplasmic streaming which forms cell extensions called pseudopodia.. The prey is digested by enzymes and the digested parts are absorbed into the cytoplasm. Amoeba reproduces by binary fission. Many species are parasites of animals and humans causing dysentery.

Fig: 7.3 Ameoba

.3. Apicomplexes or sporozoans

Apicomplexes are spore-forming parasites of animals. They are called apicomplexes because of unique arrangement of fibrils, microtubules, vacuoles and other cell organelles at one end of the cell. The best-known apicomplex is the malarial parasite Plasmodium. Female Anopheles mosquito is the carrier of Plasmodium.

When an infected female Anopheles mosquito bites a person, sprorozoites are injected into the blood stream. Sporozoites are carried to the liver where they stay and divide forming large number of merozoites. Merozoites emerge from the liver and invade red blood cells and start producing more merozoites within these cells. The infected red blood cells burst releasing the merozoites which again enter other red blood cells. The host at this stage starts showing the symptoms of malaria including chill and fever accompanied by nausea, vomiting and severe headache.

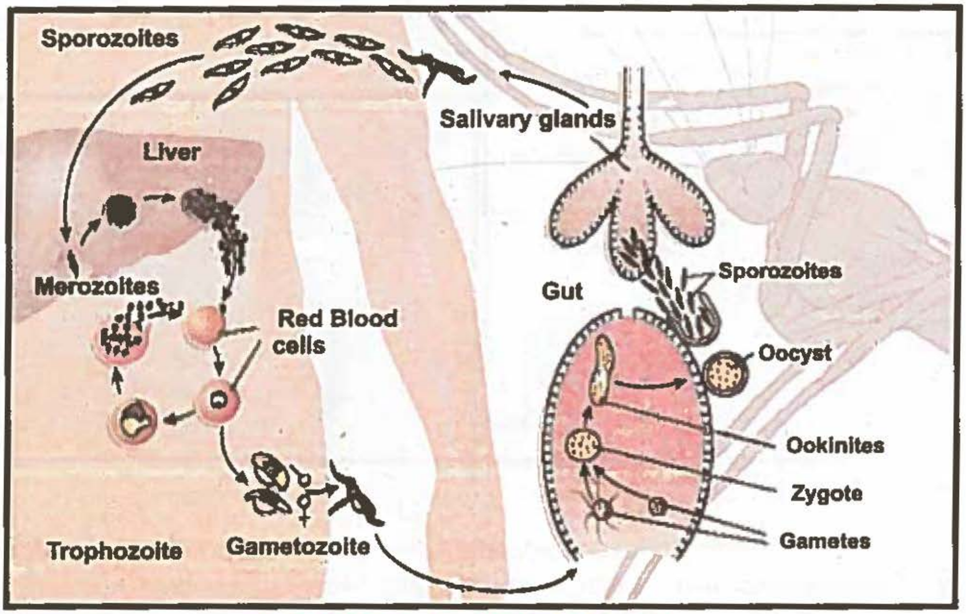


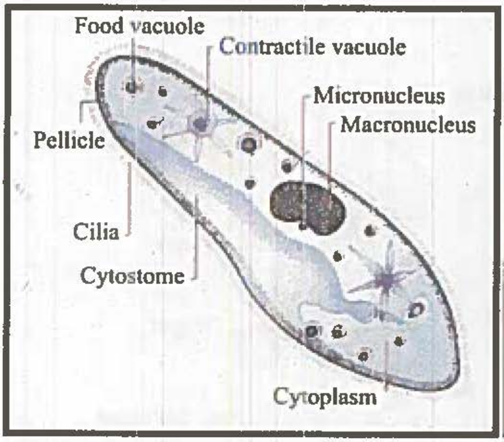
Fig: 7.4 Life Cycle of Malarial Parasite

Some of the merozoites develop into male and female gametes. If the inflected human host is again bitten by a female Anopheles mosquito, these gametes are taken up by the mosquito and sexual reproduction starts. The male gamete fertilizes the female gamete to produce a zygote. The zygote reaches the mid gut of the mosquito and then encysts forming an oocyst. The oocyst produces a number of sporozoites and transfer to the salivary glands of the mosquito. When this mosquito bites a healthy person, the sporozoites are discharged into the body of the host and a new cycle stands.

4. Ciliates

Ciliates protozoan develop a number of cilia during a part or whole of the life cycle. They use cilia for locomotion and driving food. Cilia are usually arranged in longitudinal rows or in spirals around the cell. Ciliates possess cellular organelles that perform functions similar to the organs of multicellular organisms.

All ciliates have two different types of nuclei within the cells. Small micronuclei and larger macronuclei. Macronuclei are essential for the physiological function whereas micronuclei are needed only for sexual reproduction.Ciliates form vacuoles for ingesting food and regulating water balance. Paramecium, a well know ciliate, sweeps the food into its gullet, from there it passes it into the vacuole where enzyme and hydrochloric acid help in digestion. The digested material is absorbed into the body and the vacuole empties its waste material into the anal pore located in the pellicle. The waste material then leaves the cell by exocytosis.



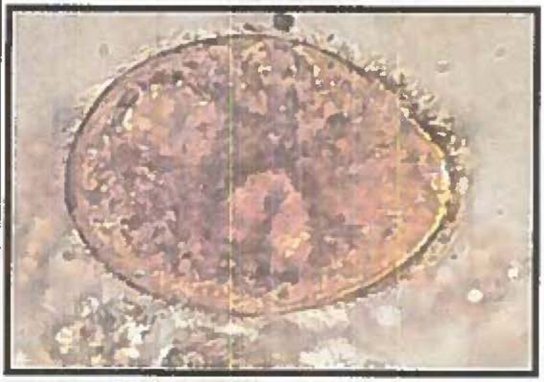


Fig: 7.5 Ciliates a. *Paramecium* b. *Balantidum coli.*

Paramecium reproduces asexually by transverse fission. It also undergoes a type of sexual reproduction called conjugation. Most ciliates live in freshwater or saltwater but they do not infect other organisms. However, *Balantidum coli* inhabits intestinal tracts of pigs and rats. People working in slaughter houses may become infected by *Balantidum coli.*

b. Plant like Portists

Plant like protists are divided into the following important groups:

1. Dinoflagellates

Dinoflagellates are unicellular autotrophs possessing chlorophyll a and c in addition to carotenoids. They live in both marine and freshwater environments. The cell wall is generally missing but when present, it is hard and made up of cellulose. They have two flagella of unequal size inserted laterally. The two flagella beat in two grooves, one encircling the cell like a belt and the other perpendicular to it.

Fig: 7.6 Dinoflagellate

As they beat, the encircling flagellum causes the organism to spin like a top; the perpendicular flagellum makes the organism move in a particular direction. In the coastal areas, the poisonous and destructive "red tides" occurs frequently. These tides are associated with great population explosions or "blooms" of dinoflagellates which change the colour of the water to red.

2. Diatoms

Each diatom is made up of two shells made of silica which are strikingly and characteristically marked. The shells of diatoms are like small boxes with lids, one half of the shell fitting inside the other. Their chloroplasts containing chlorophyll a and c, as well as cartenoids, resemble those of dinoflagellates. The shells of fossil diatoms often form thick deposits on the ocean floor which is called diatomaceous earth which is used in water filters, paints and nail polishes. Most diatoms reproduce asexually, sexual reproduction is not common.

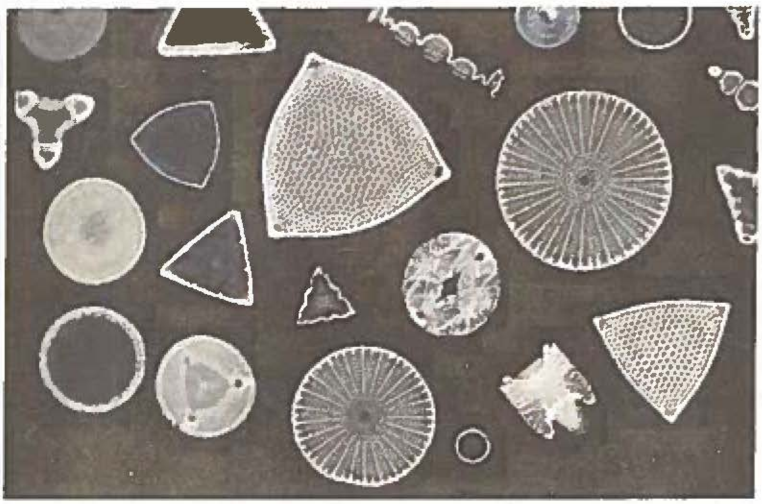


Fig: 7.7 Diatom Gallery

3. Brown Algae

Brown algae are the most conspicuous seaweeds. They possess air bladders which keep them afloat during high tides. The life cycle of brown algae is marked by an alternation of generations between a diploid sporophyte and a haploid gametophyte. Kelps are brown algae possessing large leaf-like thallus. They are important source of food for fish, bird and other marine animals. Some genera of kelps attain a length of about 100 meters. They are attached to the rocks on ocean floor through a root-like structure called holdfast.

4. Rhodophyta

The reddish colour of the algae is due to red accessory pigment called phycoerythrin which masks the green colour of chlorophyll. But red algae do not always appear red. Some exhibit different colours depending upon the type and amount of photosynthetic pigments present in their chloroplasts. The red algae play a major role in the formation of coral reefs and produce glue-like substances such as agar and carrageenan that make economically important.

5. Chlorophyta

Chlorophyta include both unicellular and multicellular forms. Most forms are aquatic but some live on moist places on land. They show many similarities to land plants; they store food as starch, cell wall is made up of cellulose and possess similar chloroplast structure containing chlorophylls a and b. it is because of these similarities that chlorophyta are considered ancestors of plants.

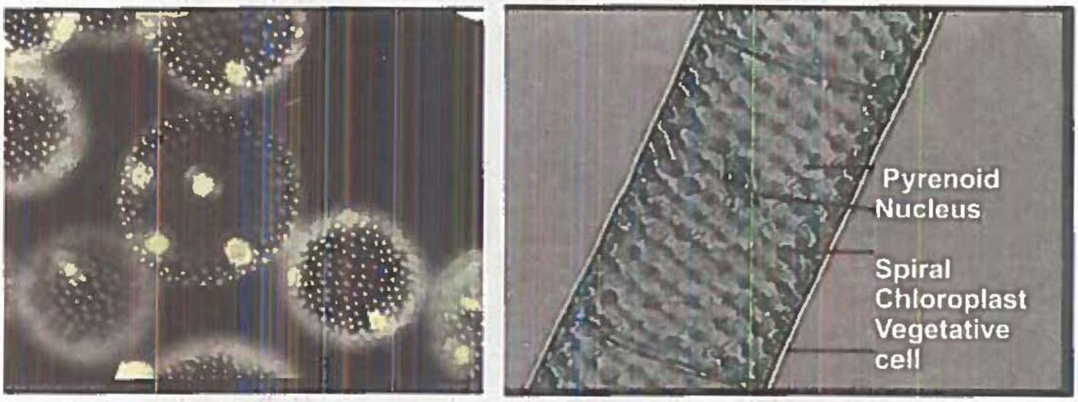


Fig: 7.8 a. Volvox b. Spirogyra filament

Chlamydomonas is a unicellular genus whereas volvox represents the colonial form. Spirogyra is a multicellular, filamentous green alga inhabiting the freshwater. Each cell of spirogyra contains one or more spiral chloroplasts. Asexual reproduction occurs through zoospores. Sexual reproduction is conjugation.

c. Fungus like Protists

Main groups of this category of protests are given below.

1. Plasmodial slime molds (Myxomycota)

Slime mold takes many forms. The most common forms on turf resemble small purple or black ball attached to a blade of grass or a readily noticeable creamy-white, yellow-orange, purple, or gray jelly-like mass situated on the lawn.

The colonies of slime mold living on logs and bark mulch can be strikingly colorful in yellow, orange or red. At one stage of their life cycle, they form a mass called a plasmodium which grows in size but does not become multicellular and remains a single mass of cytoplasm which is not divided by plasma membrane. It contains many diploid nuclei.

This "supercell" (plasmodium) is the product of mitotic nuclear divisions which are not followed by cytokinesis.

The cytoplasm in plasmodium streams back-and-forth which helps in distributing nutrients and oxygen. The plasmodium extends pseudopodia through moist soil, leaf litter or rotting logs engulfing and digesting food particles, bacteria and yeasts by phagocytosis. When the food or moisture exhausts, the plasmodium stops growing, moves to a new area and produces fruit bodies containing spores. Meiosis occurs in flagellate gametes. The gametes fuse in pairs and form a new plasmodium by mitosis.

2. Oomycota (water molds)

All the members of oomycota are either parasites or saprophytes. They are distinguished from other protists by their zoospores which bear two unequal flagella, one pointed forward and the other backward. Because of some similarities, oomycota were previously placed with fungi, but there exist many differences between the two groups. In oomycota cell wall is made up of cellulose whereas it is of chitin in fungi. Although oomycota descended from plastid bearing ancestors, yet they do not possess plastids and cannot bring about photosynthesis. Water molds living as parasites on aquatic animals produce white fuzz on the body of their host.

Importance of Protista to Humans

Protista play fundamental role in the ecosystem of world. These organisms form the foundation for food chains, produce the oxygen we breathe and play important role in nutrient recycling. Some protists are harmful but many more are beneficial. Many are economically useful as well. As many more of these unique organisms are discovered, humans will certainly enjoy the new uses and benefits protista provide.

Algae are the protista which play the most beneficial role for humans. Many form the basis of food chain which drives the wheel of life on earth. They prepare food for other organisms through photosynthesis. It has been estimated that upto one-quarter of world's photosynthesis is performed by algae and its associates. The planktons play a major role in photosynthesis in aquatic ecosystem. The vast majority of planktons in the ocean consist of various protists.

Protista are also responsible for decomposing the organic matter and recycling the nutrients. Euglena is used to treat sewage because of its ability to switch from an autotrophic to a heterotrophic mode of nutrition. Protists form a wide range of symbiotic relationship with other organisms. *Trichonympha* lives in the digestive system of terminates and produces cellulose, an enzyme that enables termites to digest wood.

Fig: 7.9 *Trichonympha*

Animal-like protists are responsible for diseases such as malaria, amoebic dysentery, African sleeping sickness and giardiasis in humans. *Phytophthora infestans* causes late blight of potato and great potato famine of Ireland in 1840s was due to the destruction of potato crop by this protist.

Some protists have medicinal and industrial uses. Carrageenan, a glue-like substance from algae is used to produce a thicknening agent in ice cream, pudding and dairy products. Chemicals from algae are used to manufacture waxes, plastics and lubricants. Other chemicals made from protists are utilized in medicines used in the treatment of ulcers, hypertension and arthritis.Many species of red algae are consumed as food in some countries. Red algae are rich in vitamins and minerals.

7.2 Kingdom Fungi

Fungi were regarded as plants because of the presence of certain characters since the last many decades, but detailed studies have revealed a set of characteristics that distinguish fungi from plants. Fungi lack chlorophyll, while the plants have this pigment; wall of a fungal cell is made up of a carbohydrate called chitin not found in plant cell walls; though generally filamentous, fungi are not truly multicellular like plants, because the cytoplasm of one fungal cell is continuous through pores with the cytoplasm of adjacent cells; and fungi are heterotrophic eukaryotes, while plants are autotrophic. It is mainly because of these reasons that fungi are placed in their own kingdom fungi.

Fungi are generally saprophytes and are the most important decomposers in terrestrial ecosystem. Many fungi are also known as parasites of animals and plants. They are found everywhere. They also develop symbiotic association with other organism. Recent finding are that fungi are more closely related to animals than plants. It is believed that fungi evolved from a unicellular flagellated ancestor. The ancestors of fungi and animals diverged into separate lineages about one billion years ago.

Do You Know?

Armillaria ostoyae
(Honey Mushroom)
World's largest organism

A single mycelium can produce upto one kilometers long new hyphae in one day. World's largest organism is a fungus called Armillaria Ostoyae (honey mushroom) growing on stumps and roots of trees in Seattle, Washington. A single colony of fungus covers 8.9 km^2 areas. It weighs 100 tons and is about 1000 years old. Most parts of the fungus lie hidden beneath the ground. It periodically produces edible fruit bodies (mushroom) above the ground.

7.2.1 General Characteristics of Fungi

1. Fungi are heterotrophic

Fungi obtain their food by secreting digestive enzyme into substrates. Then they absorb the organic molecules released by the enzymatic action.

2. Fungi have several cell types

Multicellular fungi are filamentous and the filaments are in the form of long slender structures called hyphae. Sometimes the filamentous form is lost and the hyphae are arranged in complex structures such as mushrooms.

3. Chitin cell wall

The cell walls of fungi are made up of chitin, a nitrogen containing polysaccharide, which is more resistant to decomposition than cellulose.

4. Nuclear mitosis

Mitosis in fungi is different from that in plants and animals. The nuclear envelope does not break and reform. Mitosis occurs in nucleus with nuclear membrane intact.

7.2.2 Classes of Fungi and their Diagnostic Features

a. Zygomycota

The members of the class are all terrestrial. They possess coenocytic hyphae. They live on decaying organic material. Zygomycota are characterized by the formation of sexual spores called zygospores formed by the mating hyphae. Both sexual and asexually produced sopores are dispersed by air.

Some members of the class are responsible for the rotting of bread, peaches, strawberries and sweet potato during storage; other live as parasites or symbionts of animals. *Rhizopus stolonifer*, the common bread mold, is an important member of zygomycota. The hyphae form a white or grey mycelium on bread. In asexual phase upright sporangiophores arise each of which bears a sporangium at its tip. Thousands of spores are formed in each sporangium. The haploid spores are dispersed by air. Spores, when land on moist food, grow into new mycelia.

b. Ascomycota

The characteristic feature of ascomycota is the production of sexual spores called the ascospores within saclike asci (singular, ascus); thus, they are commonly called sac fungi. Unlike zygomycota, the most ascomycota bear their sexual states in fruit bodies called ascocarps which range in size from microscopic to macroscopic. Asci are produced in ascopcarps. Most of the ascomycota also reproduce asexually by means of conidia, produced in chains at the end of a conidiophores.

Some of the ascomycota parasitize crops and ornamental plants causing powdery mildew.

Certain members of the class are extremely beneficial. Many ascomycota are the decomposers of plant material. More than 40% live with green algae and cyanobacteria in beneficial symbiotic associations forming lichens. Some form mycorrihizae with roots of higher plants. Penicillin, the wonder drug, is obtained from a fungus called pencillium. Yeast is useful for both bakers and brewers.

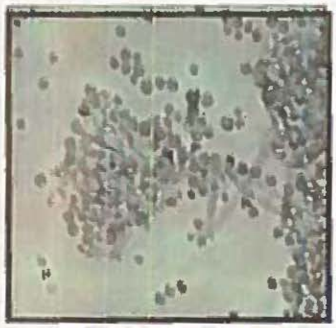


Fig: 7.10 Pencillium

c. Basidiomycota

Basidiomycota not only include mushrooms, puffballs and shelf fungi but also important pathogen like rusts and smuts. They are also known as club fungi because of their club-shaped basidia. The mycelium in basidiomycota exists in three forms i.e. primary, secondary and tertiary mycelium. Primary mycelium is also called monokaryon in which each cell is unicucleate possessing a halploid nucleus. Secondary mycelium is formed by an interaction with primary mycelium.

It consists of dikaryotic cells in which each cell possesses two haploid nuclei. When the mycelium becomes more complex and gives rise to fruit bodies (basidiocarps), it is called tertiary mycelium. Club-shaped basidia are arranged inside a fruit body called basidiocarp. Karyogamy occurs in basidium which is followed by meiosis forming four haploid nuclei which are incorporated in basidiospores.

Sexual reproduction occurs through classical methods found in other groups of fungi. Sexual reproduction in basidiomycota differs from all other groups of fungi. No reproductive structures such as antheridia and oogoina are formed. The sexual reproduction involves the conversion of monokaryotoc phase to dikaryotic phase by various methods.

7.2.3 Importance of Fungi

1. Fungi in pharmaceutical industry

Fungi have been used medicinally since ancient times. Ergotamine obtained from *claviceps purpurea* is used to facilitate delivery of babies and also used to relieve migraine headache. Pencillin, the first discovered antibiotic is produced by pencillium chrysogenum and other related species. Cephalosporin is most widely used broad spectrum antibiotic, obtained from cephalosporium acremonium and related species. Griseofulvin is an antibiotic used effectively against fungal infections of hair, nails, skin, athlete's foot and ringworm.

It is obtained from a species of *Pencillium.* Broad spectrum antibiotic cyclosporine used as a immunosuppressant drug in organ transplantation is also a fungal product.

2. Fungi in food industry

Yeast has been used by humans throughout recorded history. *Saccharomyces cerevisiae,* (yeast) is used in baking and wine making industry. It has got the ability to ferment carbohydrates, breaking down glucose to produce ethanol and carbon dioxide. It is fundamental to the production of bakery products, bear and wine.

3. Fungi used in research projects

Yeasts are mostly used in the biological research projects due to their rapidly increasing generation time and increasing pool of genetic and biological information. In soft drink industry *aspergillus* sp. is used to produce citric acid for colas.

4. Edible fungi

Mushroom is considered popular food throughout the world. Mushroom pizzas are famous for their taste. The peculiar flavor and taste of certain types of cheese come from the fungi used in the processing. The ascocarp of *Morchella esculanta* (a morel) and *Tuber melanosporum* (a truffle) are highly prized for their complex flavor.

Fig: 7.11 Mushrooms

Ectomycorrhizae of some plant families are also edible. Yeast is also used as a nutritional supplement because it contains high levels of B vitamins and about 50 percent of yeast is protein.

5. Symbiosis

Fungi develop many symbiotic associations with other organisms lichens and mycorrhizae are the examples of this relationship.

a. Lichens

In a lichen, a fungus develops a symbiotic association with an alga in which alga is the photosynthetic partner. It is an excellent example of mutualism in which both the partners are benefited. Most of the visible body of the lichen consists of its fungal partner. Interspersed with the hyphae of the fungus, there are found cyanobacteria, green algae or sometimes both. Specialized fungal hyphae penetrate the cell walls of algal partner and transfer nutrients directly to fungus. Biological signals sent out by fungus direct its algal partner to produce metabolic substances that it does not produce when growing independent of fungus.Lichens are known as pioneers in ecological succession in extremely harsh habitats. Lichens are often strikingly colored because of pigments that play a role in protecting the photosynthetic partner from the destructive action of the sun's rays. These pigments can be extracted from lichens and used as natural dyes.

Fig: 7.12 Lichens are common primary colonizers of surfaces. This rock surface has a variety of lichens growing together and adjacent with one another.

b. Mycorrhizae

The roots of about 80% of all known species of vascular plants normally are involved in mutualistic symbiotic relationships with fungi. The association is called mycorrhizae. The fungus in a mycorrhiza increases total surface area of root system for soil contact and absorption.

Mycorrhiza helps in the direct transfer of phosphorus, zinc, copper and other nutrients from the soil into the roots. The vascular plant supplies organic carbon to the fungus.

There are two principal types of mycorrhizae. In endomycorrhizae, the fungal hyphae penetrate the outer cells of the plant root, forming coils, swellings and minute branches and also extend out into the surrounding soil. In ectomycorrhizae, the hyphae surround but do not penetrate the cell walls of the roots.

6. Fungi as recycler

Fungi and bacteria are the principal decomposers in biosphere. Saprophytes exceed parasites in number in the ecosystem. They decompose the organic matter and release the substances locked in the dead bodies of plants and animals for circulation in the ecosystem. They possess a powerful enzyme system which helps in breaking down tough organic compounds like lignin, a major constituent of wood. The substances thus released become available to the next generation of organisms. Fungi recycle the nutrients in nature and are called recyclers. The fungi clean the earth by removing the organic matter and because of this characteristic they have earned the name scavenger.

7. Fungi as food spoilers

Fungi also destroy food which is not properly preserved. It includes bread, jams, cooked food etc. Fungi secrete substances into the food which make the food unpalatable, carcinogenic and poisonous.

8. Pathogenic fungi

. Fungi can cause different fatal disease in living organisms. Some of the significant pathogenic effects of fungi are discussed below.

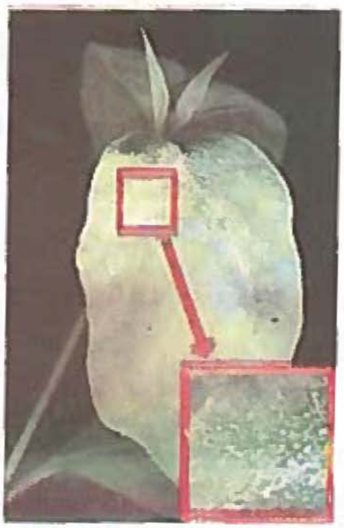


Fig: 7.13 Powdery mildew on a leaf

a. Plant diseases

Fungal diseases of plants are known to us since ancient times. Fungi are the serious agricultural pests. Most common fungal diseases of cereals are rusts and smuts caused by species of *Puccinia* and *Ustilago* respectively. Sometimes about 50 percent of world's fruit harvest is lost to fungal attack each year. Peach leaf curl, pear leaf spot and mildews are the diseases of fruits. Red rot of sugarcane, potato blight, late blight of tomato and many more diseases of plants are caused by fungi.

b. Animal diseases

Ringworms in dogs and horses are caused by the species of *Trichophyton* and *Microsporum*. *Aspergillus* sp. cause abortion in many animals *Saprolegnia parasitica* is the parasite of carp and salmon fish.

Fig: 7.14 Ringworm in dog.

c. Fungal diseases

Almost all parts of human body are infected by fungi especially the skin. Rhizopus and Mucor species cause the infection of lungs, brain and gastric tissues. The cause of dandruff is *Microsporum furfur*. *Candida sp.* cause throat and mouth diseases, pulmonary infection, diseases of nails and genital organs. *Neurospora and Fusarium* cause infection of corneal tissue of eye. Aspergillosis, whose symptoms resemble those of tuberculosis, is caused by *Aspergillus sp.* Athletet's foot is also a fungal disease.

KEY POINTS

- The kingdom protista consists of prokaryotic organisms including unicellular , colonial or very simple multicellular ones.
- In the coastal areas, the poisonous and destructive "red tides" are associated with great population explosions or "blooms" of dinoflagellates which change the colour of the water to red.
- Apicomplexes have unique arrangement of fibrils, microtubules, vacuoles and other cell organelles at one end of the cell. The best-known apicomplex is the malarial parasite Plasmodium.
- Kelps are brown algae possessing large leaf-like thallus.
- The shells of fossil diatoms often form thick deposits on the ocean floor which is called diatomaceous earth.
- Oomycota are either parasites or saprophytes. They are distinguished from other protists by their zoospores which bear two unequal flagella, one pointed forward and the other backward.
- The reddish colour of the algae is due to red accessory pigment called phycoerythrin which masks the green colour of chlorophyll.
- Chlorophyta show many similarities to land plants; they store food as starch, cell wall is made up of cellulose and possess similar chloroplast structure containing chlorophylls a and b. Because of these similarities that chlorophyta are considered ancestors of plants.
- Choanoflagellide are most likely the common ancestor of the sponges and all animals. They include three groups i.e. Amoebas, Forminaifera and Plasmodial slime molds.
- Algae are the protista which play the most beneficial role for humans.

EXERCISE

A. Choose the correct option of each statement and encircle it.

1. The protist which lives in the gut of termites and digests wood belongs to the group:
   a. Euglenozoa b. Kinetoplastid
   c. Stramenopila d. Rhodophyta
2. Which of the following is the infective stage of malarial parasite?
   a. Merozoite b. Sprorzite
   c. Oocyst d. Ookinite
3. Plasmodium of slime molds contains:
   a. One haploid nucleus b. Two diploid nuclei
   c. Many haploid nuclei d. Many diploid nuclei
4. Symptoms of malaria appear when:
   a. Gametes are produced b. Red blood cells burst
   c. Sporoazoites enter the liver d. Oocyst is formed
5. Presence of air bladder is associated with which of the following organism?
   a. Paramecium b. Euglena
   c. Volvox d. Kelps
6. In nuclear mitosis of fungi, the nuclear membrane:
   a. dissolves b. remains intact
   c. shrinks d. fuses with genetical material
7. Dikaryon is a cell in fungi containing:
   a. one diploid nucleus b. Two diploid nuclei
   c. One haploid and one diploid nucle d. Two haploid nuclei
8. Mitochondria most likely evolved by:
   a. Photosynthetic cyanobacterium b. Cytoskeletal elements
   c. Endosymbiosis d. Membrane proliferation
9. The closest relative of fungi are probably:
   a. Slime molds b. mosses
   c. Green algae d. Animals
10. What term describes the close association of a fungus with the root of a tree?
    a. Rhizoid b. Llichen
    c. Mycorrhiza d. Endophyte

11. Members of which phylum produce a club shaped structure that contains spores?

a. Chytridiomycota b. Basidiomycota

c. Glomeromycota d. Ascomycota

2. Write short answers of the following questions.

1. What were the consequences of cells undergoing the process of endosymbiosis?
2. What do you understand by red tides?
3. Why asexual reproduction is critical for the survival of fungi?
4. Why fungi are considered a threat for crops?
5. Discuss the role of algae in maintaining the oxygen balance in the biosphere.
6. What do you understand by symbiosis?
7. How will you justify the name scavengers given to fungi?
8. Discuss the medicinal importance of *claviceps purpurea*.
9. Discuss the economic importance of yeast.

C. Write answers of the following questions in detail.

1. Describe the salient features of class ascomycota.
2. Discuss the general characteristics of fungi.
3. Given an account of the class basidiomycota.
4. Discuss the beneficial aspect of fungi.
5. Given an account of human and animals diseases caused by fungi.

Projects:

- Collect five sample of algae from your local environment. Preserve them in glass bottles. Take guidance from your teacher for their scientific identification.
- Collect some local mushrooms from your environment and make a list of edible and poisonous mushrooms.
- Search some fungi which are source of antibiotic.

Chapter 8

Diversity Among Plants

At the end of this chapter the students will be able to:

- Outline the evolutionary origin of plants.
- List the diagnostic features shared by all plants, with emphasis on alternation of generation.
- Describe the general characteristics of bryophytes.
- Outline the life cycle of moss.
- Explain the land adaptations ofibryophytes.
- List the advantages/uses of bryophytes.
- Describe the general characteristics of vascular plants.
- List the characters of seedless vascular plants with examples of whisk ferns, club mosses, horsetails and ferns.
- Explain the evolution of leaf in vascular plants.
- Outline the life cycle of ferns.
- Describe vascular plants as successful land plants.
- Summarize the importance of seedless vascular plants.
- Describe the evolution of seed.
- Describe the general characteristics and uses of gymnosperms.
- Define angiosperms and explain the difference between monocots and dicots.
- Explain the life cycle of a flowering plant.
- Explain how this life cycle demonstrates an adaptation of angiosperms on land.
- Define inflorescence and describe its major types.
- Describe the significance/benefits of angiosperms for humans.

Introduction

Virtually all other living creatures depend on plants to survive. Plants are found on land, in oceans, and in fresh water. They have been on Earth for millions of years. In order to study the billions of different organisms living on earth, biologists have sorted and classified them based on their similarities and differences. All plants are included in one kingdom (Kingdom *Plantae*), which is then further divided into smaller divisions based on several characteristics. The majority of the plant species are flowering herbs. Some are non vascular and other are vascular based on the presence and absence of conducting tissues. Still there is a group of plants that reproduces from spores rather than seeds, and the other that reproduces from seeds. Indeed this diversity of plants is of great importance and invites careful study.

8.1. Evolutionary Origin of Plants

Since the origin of life on earth, various organisms have evolved and dominated the earth at different times. The fossil records of different organisms show the time period on the geological time scale when they were present abundantly on earth. The discovery of the three billion years old bacteria by Barghoon and Schopt confirmed that life even existed before that and is not younger than the origin of the earth itself.

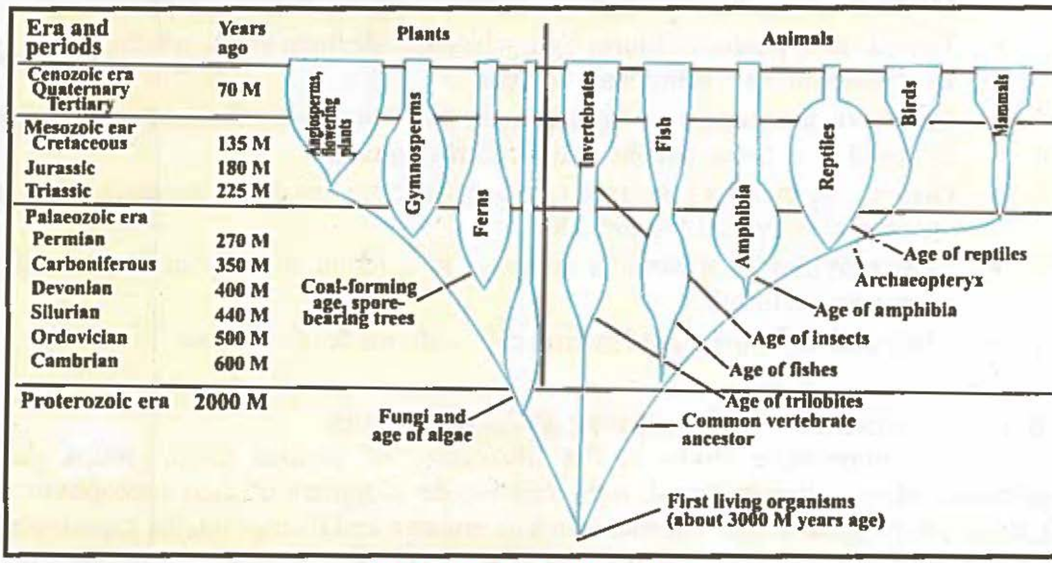


Fig: 8.1 Geological time chart

Fossils discovered by biologists provided the evidence of the dominated organisms in a particular era also, e.g. ferns flourished well and dominated the earth during the **Permian** and **Triassic** periods and ammonoid mollusks during Triassic and Jurassic period of the geological time chart.

8.1.1 Phyletic lineage

It is the sequence of arrangement of species from ancestors to the descendent through their evolution. The descendant populations have a resemblance with their ancestors in many respects as well as their immediate descendants in a certain sequence.

Phyletic lineage provides a link between the present day organisms with their remote past ancestors. The link has been established on the basis of the fossil records of both plants and animals as well as bacteria. Today almost two million species of living organisms in animals and about 0.5 million plant species have been identified by the biologists while still a large number is left unidentified.

8.1.2 Diagnostic Features of Plants

Some of the distinctive characteristics of plants are as fallows:

- Higher plants possess, independent sporophytes, which may be trees, shrubs or herbs (primitive members are trees, while shrubs and herbs are considered to be derivatives or more advanced).
- They are differentiated into roots, stem and leaves traversed by vascular strands.
- Majority of the plants are as a rule are stationary or fixed to one place.
- They usually possess chlorophyll, which enable them to manufacture complex food material from simpler substances.
- They take in materials for food from the soil in the form of solution of inorganic salts and from the atmosphere in the form of gases.
- Growth is generally restricted to places near the tips of organs and continuous at regular intervals throughout life.
- They may not be apparently sensitive to external stimuli but they can show responses to stimuli.
- Their cells are surrounded by firm cell-walls made of cellulose.

8.1.3 Evolution of Alternation of Generations

A comparative study of the life-cycles of various plant groups shows pronounced evolutionary trend in the relative development of their sporophytic and gametophytic generations. In plants such as mosses and liverworts, the gametophytic generation is larger, dominant and autotrophic due to the presence of chlorophyll, while the sporophytic generation is smaller, less complex and heterotrophic, being partially or totally dependent upon the gametophyte. In certain algae like *Ulva* and *Ectocarpus*, both the generations are independent and morphologically and structurally identical (isomorphic).

In higher cryptogams, e.g., *Lycopodium, Selaginella*, ferns and phanerogams, gymnosperms and angiosperms, the relative development of the two generations is reverse of that as described above. The sporophyte is more prominent, structurally complex and autotrophic, contains chlorophyll and is differentiated into root, stem and leaves, traversed by vascular bundles, while the gametophyte is smaller and very simple in structure. The climax of this expansion of the sporophyte and reduction of the gametophyte is evident in angiosperms, where the sporophyte is a complex independent plant while the gametophytes are tiny, microscopic structures, devoid of chlorophyll and totally dependent nutritionally upon the sporophyte. Another conspicuous feature is the presence of vascular tissues only in the sporophyte; the gametophytic generation in no case being provided with a vascular tissue.

8.2 Non-Vascular Plants

8.2.1 General Characteristics of Bryophytes

The phylum **Bryophyta** include Musci - Mosses, Hepaticae - liverworts, Anthocerotae - hornworts as classes. Bryophytes are the first plants which migrated to land Bryophytes comprise the small and simplest non flowering land plants which usually occur in moist shady places, rocks, walls and bank of rivers etc. They are non vascular plants. Thus the transportation of food, water and minerals occurs by diffusion. The plant - body is green branched thallus, lacking true roots, stems or leaves, but possessing hair like rhizoids instead of roots.

The plant body is gametophyte, which bear multicellular male and female reproductive organs called antheridia (singular antheridium) and archegonia (singular archegonium) respectively. The sex organs produce male and female gametes by mitosis. The male gametes are called sperms which are motile while the female gamete is called egg or oosphere which is non motile and one in each archegonium. The sperms swims towards the archegonium being attracted by the sweet fluid secreted by the neck of archegonium, and fuses with it to form diploid zygote.

Fusion of sperm with the egg to form oospore or zygote is called fertilization. The zygote rests in the archegonium for some time and then develops by mitosis into diploid embryo. Bryophytes are therefore, called embryophytes.

The embryo develops into diploid sporophyte which produces haploid spores by meiosis. The spores then develop into gametophyte. The sporophyte remains attached to the gametophyte for nourishment and protection. The bryophytes thus show alteration of generations, which is a useful process for successful survival of the plant. Examples of bryophytes are liverworts (*Marchantia*), hornworts (*Anthoceros*) and mosses (*Funaria* and *Polytrichum*) (Fig.8.2).

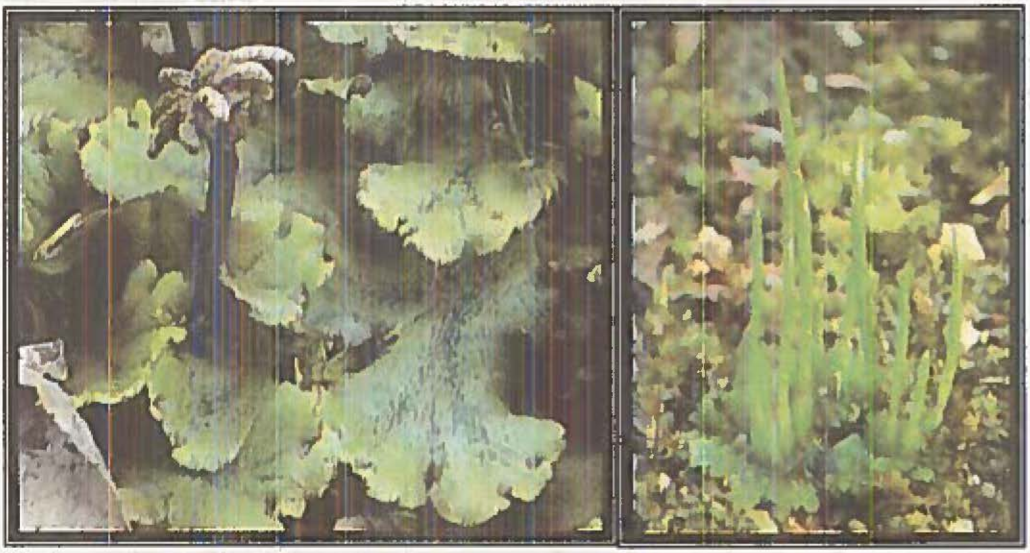


Fig: 8.2 a. Marchantia b. *Anthoceros*

8.2.2 The Life Cycle of Moss

Life-history may be studied by referring to *Funaria* or *Polytrichum*. Moss occurs most commonly on old damp walls, trunks of trees, and on damp ground during the rainy season, while in winter, it is seen to dry up. It is gregarious in habit; wherever it grows it forms a green patch or a soft velvet-like, green carpet.

Moss plant is small, about 2.7 cm or so in height, and consists of a short axis with spirally arranged, minute, green leaves which are crowded towards the apex; true roots are absent. It bears a number of slender, multicellular, branching **rhizoids** which perform the functions of roots. The axis may be branched or unbranched.

Reproduction, The moss plant is the **gametophyte**, i.e. it bears gametes and reproduces by the sexual method. For this purpose highly differentiated male and female organs are developed at the apex of the shoot. The male organ is known as the **antheridium** and the female organ as the **archegonium**. These organs are sometimes intermixed with some multicellular hair-like structures, known as the **paraphyses** (para, beside; physo, to grow or an off shoot). Antheridia and archegonia may occur together on the same branch or shoot or on two branches of the same plant (monoecious) or on two separate plants (dioecious).

The **antheridium** is a multicellular, short-stalked, club-shaped body which is filled up with numerous small cells (Fig.8.4) known as antherozoid cells. The antheridium bursts at the apex and the antherozoid cells are liberated through it in a mass of mucilage.

The mucilaginous walls surrounding antherozoid cells dissolved in water and the **antherozoids** are set free. They are very minute in size, spirally coiled and biciliated; after liberation they swim in water that collects at the apex of the moss plant after rains.

The **archegonium** is also a multicellular body, but it is flask-shaped in appearance. It is provided with a short, multicellular stalk and consists of two portions; the lower swollen portion is known as the venter (belly), and the upper tube-like portion as the neck. The neck is long, narrow and straight. Within the venter there lies a large cell which is the **ovum** (egg-cell or oosphere) or female gamete; above this lies a small ventral canal-cell and higher up in the neck there are a few neck canal-cells. Except the ovum other cells mentioned above are functionless and soon get disorganized. The neck at first remains closed at the apex by a sort of lid, but as the archegonium matures, the lid opens and allows the antherozoids to enter and pass through it.

Fig:8.3 *Funaria*

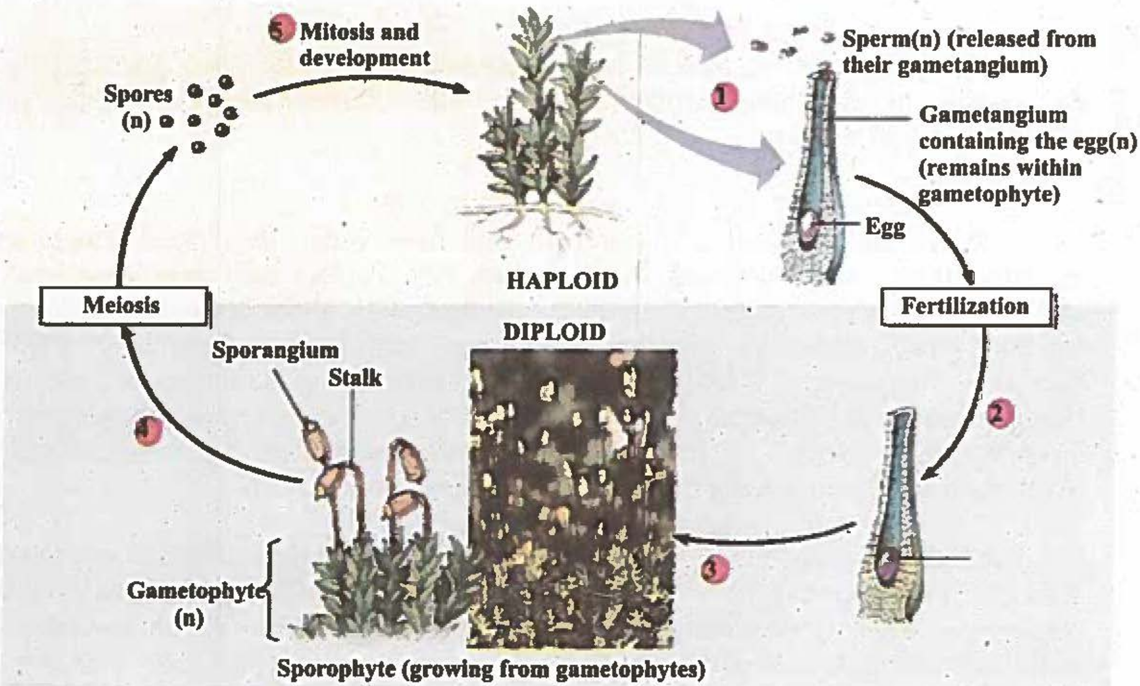


Fig: 8.4 Alternation of generation in a moss plant.

Egg and sperm fuse to form zygote which develop into sporophyte. The sporophyte plant produce haploid spores by meiosis. The spores give rise to new gametophyte plant.Examples of mosses are *Funaria* and *Polytrichum*.

For Your Information

Peat bogs and their importance

Peat bogs are areas of great natural beauty, as well as being rich in wild plants, insects and animals. Peat bogs are fed by rainwater and the soil builds up its own water table and acidity. Sphagnum mosses grow and decay eventually forming layers of peat, then peat mounds many metres deep. This process takes thousands of years, which is why sustainable large-scale peat extraction is impossible; the extraction is always faster than the growth. Habitats like these simply take too long to grow back. Peat bogs are rich in diversity of plants and wildlife, some of which are unique to these environments.

8.2.3 Land Adaptation by Bryophytes

Bryophytes had invaded the land from water and therefore, they are called the first invaders of land among the plants. They show the following adaptations for life on land or terrestrial habitat.

a. Multicellular plant body and conservation of water

When the bryophytes migrated to land from water, they faced danger of dehydration due to evaporation. To cope with this problem they developed many structures which prevented loss of water or dehydration. Plant body or thallus was made of many cells which kept the needful water with in them for successful life. Moreover for protecting dehydration due to evaporation from the surface of the cells, they formed a waxy waterproof layer called cuticle (made of cutin) on the epidermis. In spite of these adaptations, if some bryophytes are dry, they become brittle and turn green soon after getting water from rain or any other source of water.

b. Absorption of carbon dioxide

Bryophytes have evolved elaborate structures to absorb sufficient of carbon dioxide. The epidermis is provided with many pores for the diffusion of carbon dioxide and oxygen. This carbon dioxide is absorbed by the wet surfaces of the photosynthetic cells for the life processes of the bryophytes.

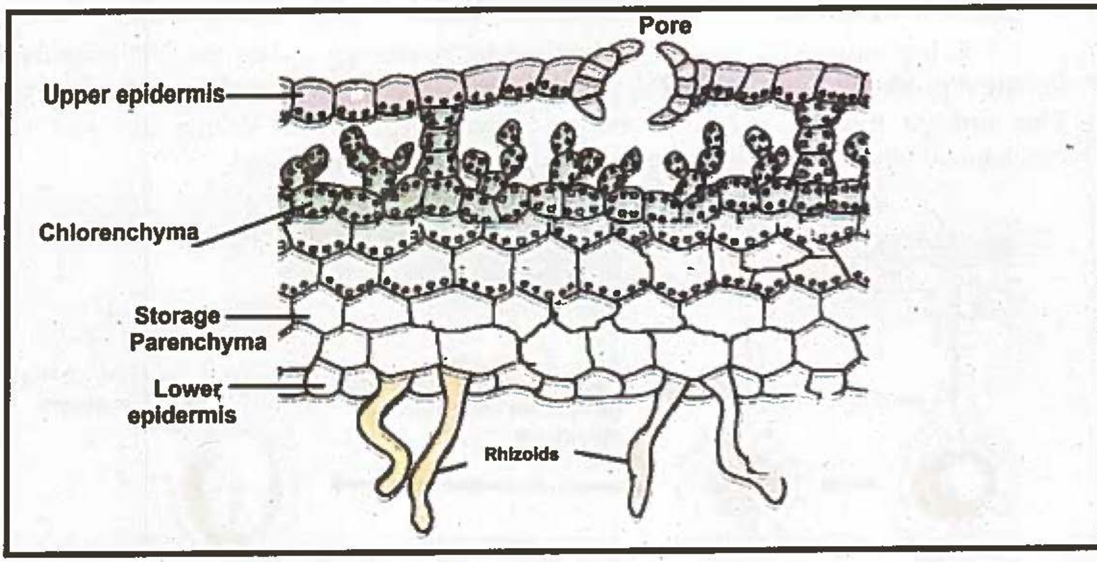


Fig: 8.5 Structure of thallus of bryophyte showing multicellular plant body and conservation of water .

c. Absorption of water

Bryophytes have no roots or root-hairs for absorbing water from the soil. They have developed long hair like structures called rhizoids from lower surface of the thallus to absorb water from the soil which enables the bryophytes to live on land.

d. Heterogamy

The universal occurrence of sexual reproduction of heterogamous type involving the union of sperm and egg in green plants like bryophytes is the most successful type of reproduction. The large, non motile egg formed in heterogamy is full of stored food. After fertilization this stored food is used to nourish the early stages in the development of new offsprings. The heterogamous sexual reproduction is best suited for life on land.

e. Protection of reproductive cells

Reproductive cells should be safe and protected from any kind of injury for the plants to live on land. Fortunately the bryophytes possess this important character which enable them to survive land habitat. The reproductive cells are sperms and egg or oosphere. The sperms remain protected in male sex organ or antheridium and the egg in the female sex organ or archegonium. The sex-organs are prevented from drying by the leaf like structures and sterile hairs produced at the shoots which bear the sex organ. Moreover the spores of these land plants are also well protected from drying. Spores are produced in multicellular sporangia.

f. Embryo formation

In bryophytes the sperms are transported to the egg and unites with it inside the female reproductive structure. A zygote is formed here which develops into an embryo. The embryo remains protected in the female organ from drying out and from mechanical injury. In this way the chances of survival are increased.

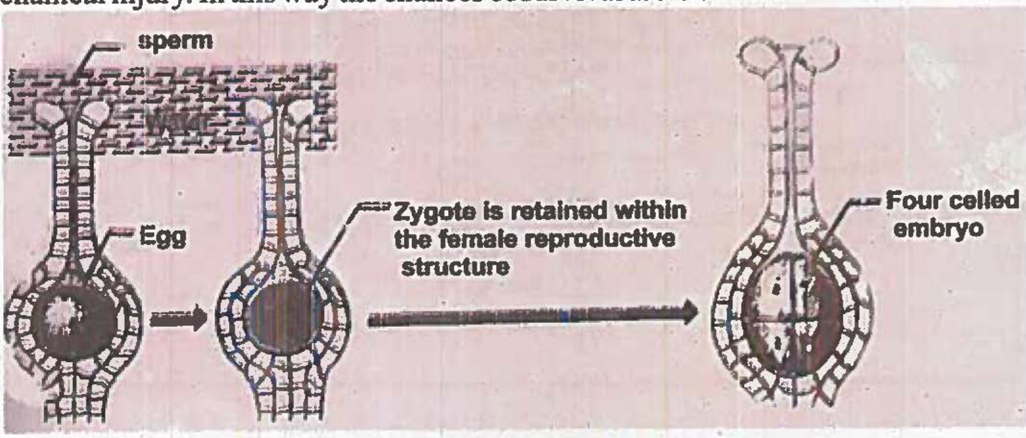


Fig: 8.6 Formation of Embryo

g. Alternation of generation

The life cycle of bryophytes shows clear alternation of generation for its survival on land. Alternation of generation is an adaptation to land habitat which ensures diversity and variations in characters. These variations help the plant to adjust and survive the land habitat.

8.2.4 Uses of Bryophytes

Bryophytes have many useful economic values e.g.

1. A kind of moss - *Sphagnum* or peat moss is used (when fresh) as a packing material by the horticulturists, for it can take up and hold large quantities of water. Remains of this moss become peat which is used extensively as a fuel.
2. Through their chemical and physical actions, rocks are broken down into simple soil - constituents.
3. The decay of their dead bodies builds up the much needed organic matter of the soil.
4. Make habitat suitable for new plants.

8.3 General Characters of Vascular Plants (Tracheophytes)

Tracheophytes form a large and diverse group of the present day land plants. They include most of the dominant land plants. They are called vascular plants because of the presence of vascular tissues. They are called tracheophytes because all of them have cells called Tracheids.

Tracheids are water - conducting cells of xylem. In tracheophytes the sporophyte generation is dominant and the gametophyte small reduced and short lived. Tracheophytes form successful group of land plants because they can adapt themselves even to rough land as well. They can save themselves from high temperature by transpiration and can gain a large height without facing any problem of water supply. Vascular plants are divided into two major sub - divisions namely lower vascular plants and higher vascular plants. In the lower vascular plants seeds are not produced. They reproduce by spores e.g. *Rhynia, Psilotum*, club mosses, horse tails and ferns.

The higher vascular plants are seed producing plants i.e. gymnosperms and angiosperms.

Tracheophytes furnish us with the very necessities of life --- namely all of our food, wood for construction of our houses, fibers for clothing, medicines and fuels such as coal. The herbs shrubs, and trees are tracheophytes.

The phylum tracheophyta is further divided into the following four sub - divisions or sub - phyla, or major groups.

1. Sub - Phylum: Psilopsida
2. Sub - Phylum: Lycopsida
3. Sub - Phylum: Sphenopsida
4. Sub - Phylum: Pteropsida

1. Sub - Phylum: Psilopsida

This is the oldest group of most primitive rootless, leafless vascular plants. The sporophyte body shows little organ differentiation. The stem is differentiated into an underground rhizome and an aerial part. The rhizome grows horizontally in soil and may bear rhizoids but no roots.

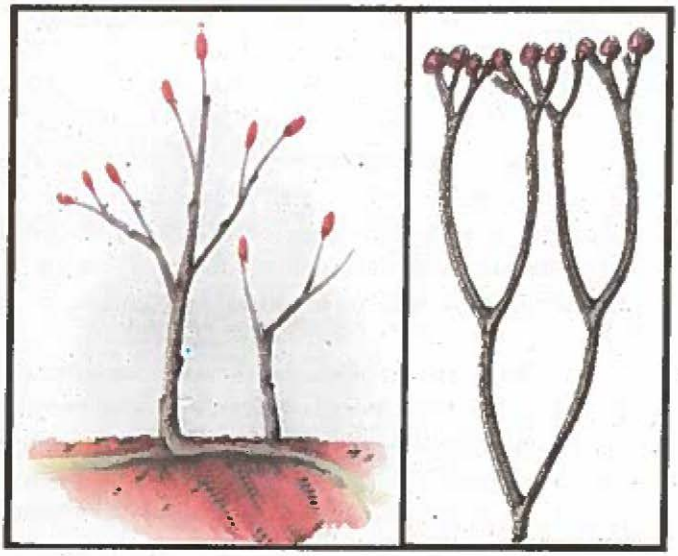


Fig: 8.7(A) a. *Rhynia* b. *Cooksonia*

The upright stem shows dichotomous or forked (Y - shaped) branching. The reproductive organs are sporangia (singular: sporangium) which are produced at the tips of the branches. The spores are formed in the sporangia. The two living genera are *Psilotum* and *Tmesipteris*.

Examples of *Psilopsida* are *Rhynia, Cooksonia, Psilophyton (Psilopsidom), Psilotum* and *Tmesipteris*.

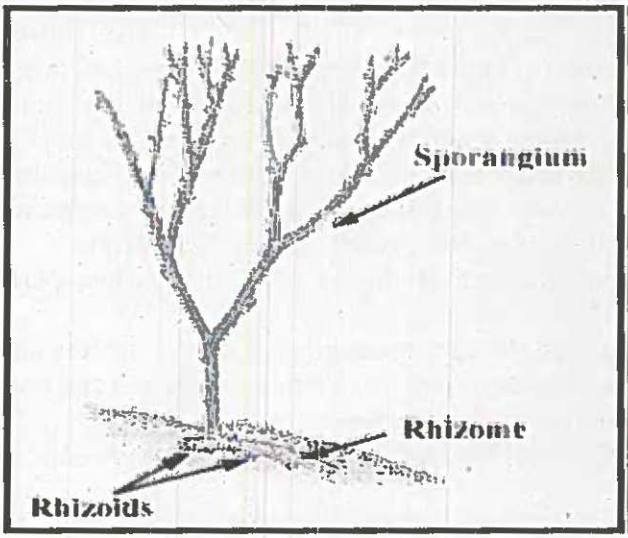


Fig: (B) 8.7 a. *Psilotum* b. *Psilophyton*

2. Sub - Phylum: Lycopsida (clubmoss)

Lycopsida includes both the living and fossil genera. The living genera are *Lycopodium, Selaginella, Isoetes* and *Phylloglosum*. The fossil genera are *Lepidodendron* and *Sigillaria* etc. The plants of lycopsida are sporophytes, differentiated into roots, stem and true leaves. The leaves are small simple and are called microphyllus (one veined leaf) leaves.

Characteristics of Lycopsida

The leaves usually densely surround the stem. Branching is basically dichotomous. The spores are formed in the sporangia. The gametophyte of lycopsida is large, underground and independent. The sporangia develop singly on the upper side of the sporophylls. The sporophylls usually form strobili. At the base of sporophylls is present a small outgrowth called ligule to retain moisture. In some lycopsida such as *Lycopodium*, the ligule is absent.

Lycopsida are commonly called club mosses. They are not mosses but called club mosses because their strobili are club shaped and their leaves resemble the mosses. One example is *Selaginella*.

Selaginella

General Characters

Selaginella comprises over three hundred species, most of which are tropical and grow abundantly on hills. *Selaginella* grows in damp places in the hills and in the plains. It is a slender, much-branched plant, either creeping on the wall or on the ground.

The slender stem bears four rows of leaves--two rows of small leaves on the upper surface and two rows of larger leaves at the two sides. A long slender, root-like organ is given off from the stem which is known as the **rhizophore** (root-bearer).

Selaginella plant is the **sporophyte**. It bears two kinds of sporophylls - **microsporophylls** and **megasporophylls**. Both kinds of sporophylls may occur together in the same cone, or they may be borne in two separate cones either on the same plant or on two separate plants. All the sporophylls are nearly of equal size and spirally arranged, usually in four rows, round the apex of the reproductive shoot, in the form of a more or less distinct four-angled cone, called the **sporangiferous spike** or **strobilus**. The sporophylls are similar to the vegetative leaves in appearance, but are smaller in size.

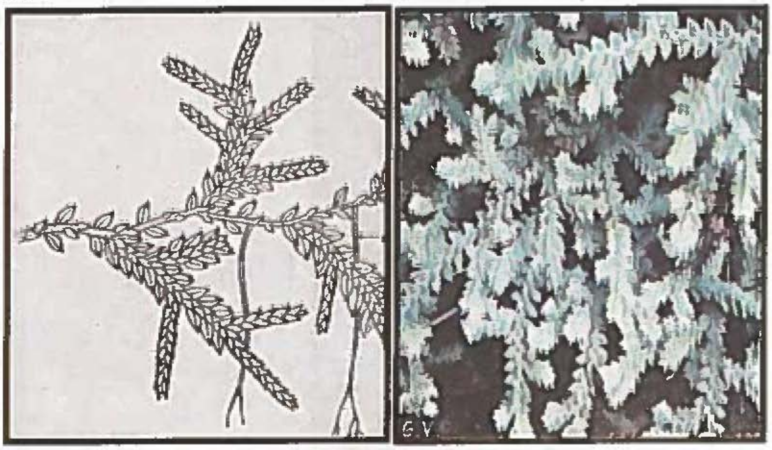


Fig: 8.8 *Selaginella denticulata*

3. Sub - Phylum: Sphenopsida (horse tails)

This group includes both extinct (e.g. *Calamites*) and living plants e.g. *Equisetum*, the only surviving genus. In this group, the individual plant is seldom more than a few feet high. The plant is sporophyte, distinguished into roots, stem and leaves. The stem is not smooth but has ridges, furrows or ribs, and divided into joints, nodes and internodes. Therefore these plants are also called arthrophytes. The leaves are reduced to scales and arranged into whorls at each node. Sporangia are closely packed to form terminal cone or strobilus.

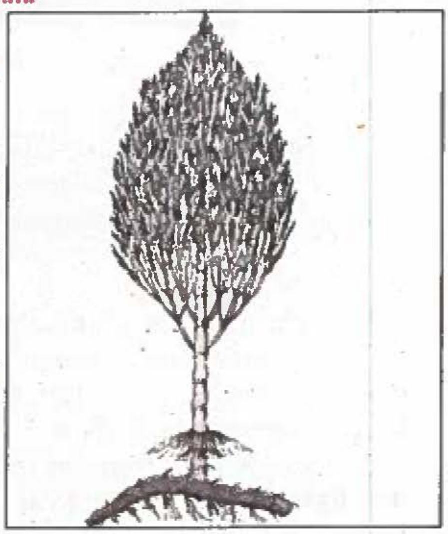


Fig: 8.9 *Calamites*

The underground stem or rhizome branches frequently and is anchored by adventitious roots usually formed at the node. The upright green branches are numerous.Special lateral appendages called sporangiophores are developed which bear sporangia. Spores are produced in each sporangium.

The mature gametophyte body is more or less flattened, irregularly shaped structure called a Prothallus. It is held to the substrate by slender root like rhizoids. The antheridia and archegonia are borne on the upper surface. There is a distinct alternation of generation.

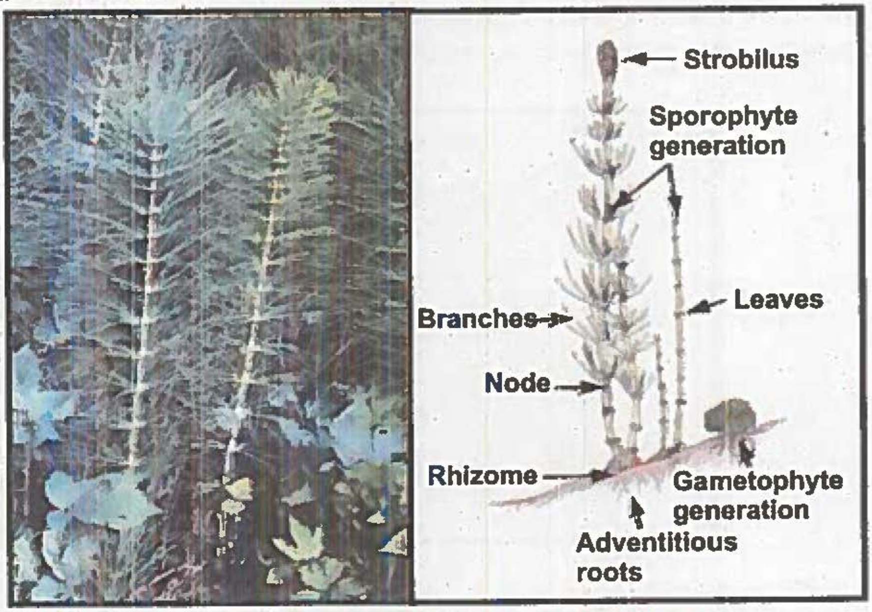


Fig: 8.10. *Equisetum*. A vegetative shoot with whorls of branches.

4. Sub Phylum: Pteropsida (ferns and seed plants)

Sub phylum pteropsida constitutes a group of the best known plants on the earth. Pteropsida is a heterogeneous group, consisting of three classes namely Filicineae, Gymnospermae and Angiospermae.

8.3.1 Class I. Filicineae

The members of this class includes ferns. Ferns have the prostrate plant body that bears numerous sporangia on the leaves called fronds. They are mostly found in moist and shady places. The plant body is divided into root, stem and leaves. Plants have a subterranean rhizome.

Roots are developed from the base of rhizome. Leaves are megaphyllous i.e. they have branched veins. Leaves or fronds are simple with a petiol or compound with a central axis or rachis. The immature and young frond is coiled, one of the important character of this group.

a: Maiden-hair fern (*Adiantum*) b. *Dryopteris* (*Aspidium*)
Fig: 8.11 Some representative of ferns

Sporangia are grouped to form sori on the under surface of leaves. Most of the plants are homosporous. Gametophyte is small, heart shaped and photosynthetically independent. The sex organs are antheridia or archegonia, produced on the under surface of gametophyte. The class filicineae comprises nearly 10000 species, which are widely distributed. Common example of this class are *Adiantum, Pteris, Dryopteris* and *Pteridium*.

8.3.1.1 Evolution of leaf

Leaf is a green mostly flat structure borne at the node on the stem or on its branches in all the vascular plants. The primary function of the leaf is photosynthesis. It also helps in transpiration. Another activity of the leaf is respiration which involves the absorption of oxygen and liberation of carbon dioxide. The primitive vascular plants lacked leaves. The stem being green was photosynthetic. It is the evolution of leaf which resulted in efficient photosynthesis.

How did this important organ of the plants arise, when none was present in the primitive vascular plants? Before we answer this question, we must distinguish between two basic types of leaves occurring among vascular plants. One kind is miscrophyllous leaf with a single vein and the other is megaphyllous leaf with many veins.

a. Evolution of microphyllous leaf

Microphyllus leaf is present in club moss and horse tails. The interpretation of the fossil record does not permit a clear answer as to how the microphyllus leaf evolved. However, there are two possibilities about the origin of microphyllus leaf.

One possibility is that this leaf originated as an outgrowth, lacking vascular tissue, from the naked branches of the primitive plant. With increase in size, it needed support and transport so vascular tissue in the form of one vein appeared in it and in this way microphyllus leaf was formed.

Another possibility is that the microphyllus leaf originated by the reduction in size of a part of the leafless branching system of the primitive vascular plant.

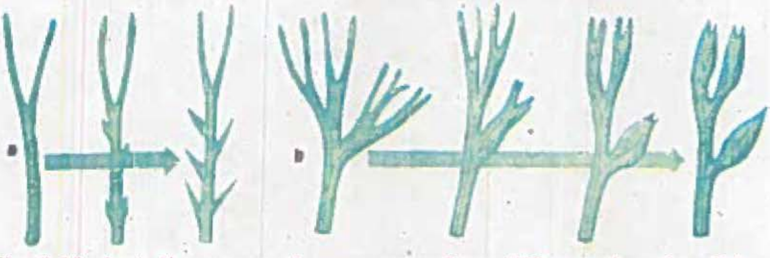


Fig: 8.12a,b: A diagrammatic summary of two different theories of the evolution of single veined leaves.

In any possibility, this simple kind of leaf became well established in groups of primitive plants such as club moss and horse tails.

b. Evolution of Megaphyllous leaf

Megaphyllous leaf is found in many plants such as leaf of *Ginkgo*. When we examine the leaves, we find that they are evolved by the evolutionary modification of the forked branching system. Therefore, this hypothesis of the evolution of megaphyllous leaf is called forked branching reduction hypothesis. The branching system became flate during the evolution of megaphyllous leaf. This step of evolution of megaphyllous leaf is called planation.

Next in evolution, the spaces between the bundles and branches of vascular tissue became filled with photosynthetic tissue. This process is called **webbing**. The organ, now a leaf, looked superficially the webbed foot of a duck. The branches changed into veins which resulted in many veined leaf or megaphyllous leaf.

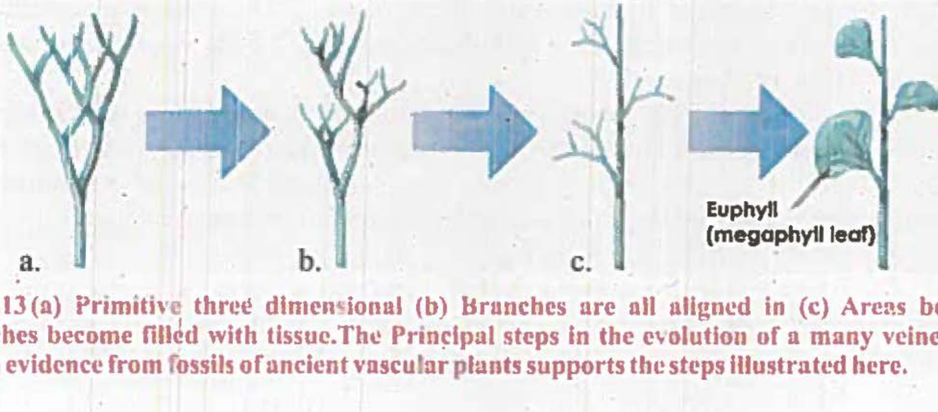


Fig:8.13 (a) Primitive three dimensional (b) Branches are all aligned in (c) Areas between branches become filled with tissue.The Principal steps in the evolution of a many veined leaf. Much evidence from fossils of ancient vascular plants supports the steps illustrated here.

8.3.1.2 *Adiantum* (Maiden-hair Fern)

a. Vegetative structure

Adiantum is a common fern, growing wild in places along the walls of wells and water courses. It is a small herb; consisting of a stem, roots and leaves. The stem is a short, thick rhizome, lying horizontally in the soil. It is usually unbranched and is covered by persistent leaf bases. The stem and the petiole are covered with numerous brownish scales known as **ramenta**.

The roots are fibrous adventitious and arise from the lower side of the rhizome. The leaves or fronds are large and compound. They arise from the upper side of the rhizome. Each leaf consists of leaflets or pinnae. The pinnae are further divided into pinnules. Each leaf consists of a stalk like portion, the stipe, which is continued above into the rachis.

b. Life Cycle of *Adiantum*

Adiantum is sporophyte. It has asexual reproductive organs called sporangia which contain spores. Sporangia are arranged in groups called sori. The spores are small and light, and are liberated from the sporangia in dry weather. When a spore falls on a suitable soil, it begins to germinate in about a week's time and produces a haploid gametophyte called **prothallus** which is capable of manufacturing its own food.

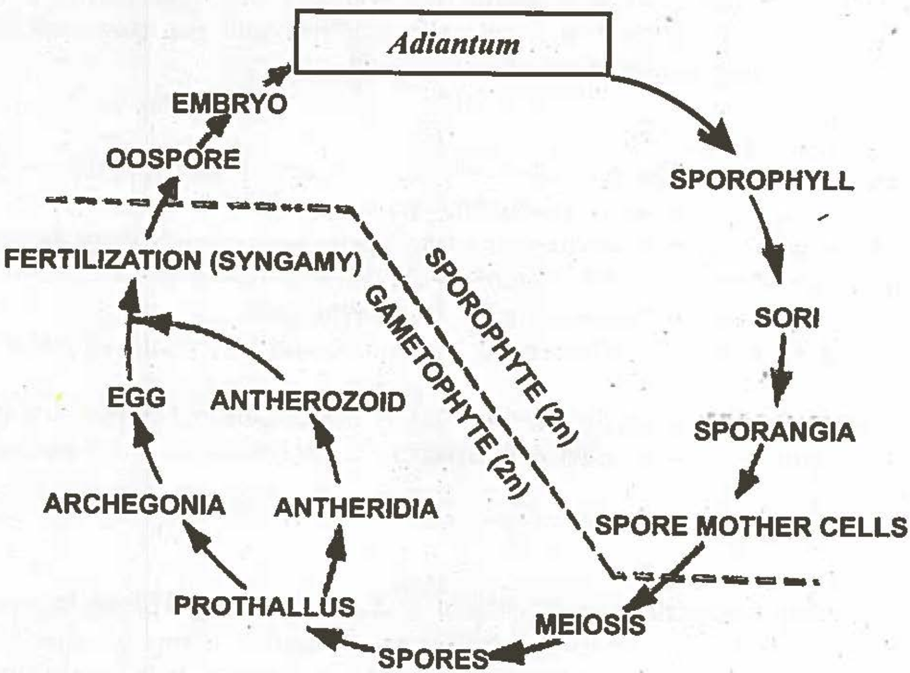


Fig: 8.14 Life cycle of *Adiantum*

The **prothallus** is green, small, flat and heart shaped structure. From the under surface of the prothallus arise a number of rhizoids. The rihzoids fix the prothallus to the soil and absorb water and mineral salts from the soil. The prothallus is hermaphrodite, bearing both the antheridia and archegonia on its under surface. Each antheridium contains sperm mother cells or spermatocytes which gives rise to a male gamete or sperm. Each archegonium is a flask shaped body consisting of a tube like neck and a basal swollen venter. The venter contains a single long naked cell called egg or oosphere.Fertilization occurs when the soil is thoroughly wet with water. A number of sperms cluster round the open mouth of the archegonium and one of them passes down to the venter fuses with oosphere to form oospore or zygote which begins to divide to produce an embryo which develops into a young sporophyte of *Adiantum*.

Alternation of Generation in *Adiantum*

The life history of *Adiantum* includes two quite distinct generations, the sporophyte generation and the gametophyte generation. The sporophyte produce spores which on germination gives rise to a heart - shaped gametophyte or prothallus. The gametophyte develops antheridia and archegonia, which contain sperms and eggs respectively. The oospore resulting from the fusion of the sperm with the egg does not give rise to gametophyte but grow into an independent young sporophyte of *Adiantum*. Thus the sporophyte gives rise to the gametophyte and the gametophyte to the sporophyte is known as alternation of generation.

8.3.1.3 Importance of seedless vascular plants

1. They are dominant plants of the world next to spermatophytes and have colonized major shady areas near water course and moist places.
2. Psilopsida, a group of seedless vascular plants have evolutionary importance as they represent connecting link between bryophytes and pteidophytes.
3. They have special role in enriching the flora of the earth.
4. Some of the ferns, e.g *pteridium* etc., are edible and their young shoots are used as vegetables.
5. Seedless vascular plants invade the habitats as a transitional community during the process of plant succession and hence perform a major role in the establishment of plant communities.

8.4 Seed Plants

8.4.1 Evolution of Seed

Seed may be defined as a fertilized and ripened ovule. The evolution of seed is the most important process in the evolution of vascular plants because seed is the structure which can survive under unfavorable conditions. It is responsible for the preservation of species. Seeds have made the plants dominant vegetation on land.
The evolution of seed involve the following steps:

a. Development of heterospory

All the seed plants are heterosporous. They produce two types of spores namely microspores and megaspores. The microspores produced in the microsporangia (pollen sac) germinate into male gametophyte and megaspore produced in the megasporangia (ovules) germinate into female gametophyte (embryo sac).

b. Retention of megaspore inside the sporangium

Instead of being shed from the sporangium like the spores of the lower plants, the megaspores of the seed plants are permanently embedded and protected inside the megasporangium. Here the megaspore develops into a small female gametophytes.

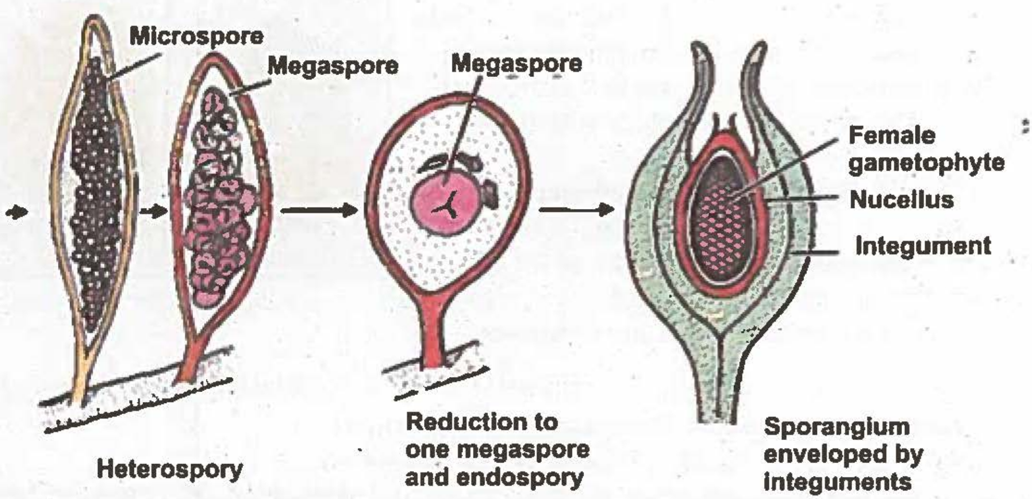


Fig: 8.15 Main steps in the evolution of seed

c. Formation of integument around the megasporangium and evolution of ovule

The fossil record shows that there were certain fern like plants that bore seeds. In this case the megasporangium was surrounded by branch like outgrowths. These outgrowths became fused, during evolution, to form an envelope like structure called integuments, around the sporangium. The integuments form protective covering. The integumented megasporangium in which the megaspore is retained is called an ovule or unripe seed.

The ovule also contains large quantity of food for the developing embryo. These two characters protection and food are the best adaptive characters of land plants to their environment to make them prominent on earth.

d. Evolution of pollen tube

The non vascular plants and the lower vascular plants require water for fertilization. They produce motile flagellated sperms that reach the non motile egg through water from rain or dew etc. However the seed plants do not depend on water for fertilization. The evolution of pollen tube parallels the evolution of seed.

The egg produced in the ovule is enclosed and protected by the integuments and the sperms would not be able to reach the egg. This obstacle is overcome by the development of pollen tube that acts as a vehicle for the transport of sperms to the eggs inside the ovule ensure fertilization. Thus the seeded plants can grow in a variety of terrestrial environments from the alpine environments of the mountains to the arid regions of the desert.

8.4.2 Class 2 Gymnospermae

1. Gymnosperm is derived from two words, gymnos means naked and sperma means seeds.
2. Gymnosperms produce seeds without fruit, borne on the surface of the scales which form a cone.
3. They bear their ovules exposed on open carpels.
4. The plant body is a sporophyte, in the form of tall woody perennial trees or shrubs.
5. The root is well developed and persistent.


Fig: 8.16 Male Cone


Fig: 8.17 Female con

6. Leaves may be dimorphic i.e. foliage leaves and scale leaves. The leaves are evergreen with thick cuticle. Stomata are sunken in pits.
7. Secondary growth occurs by the activity of cambium.
8. The reproductive structures or cones are unisexual. Both the male cones and female cones lie on the same plant (monoecious plants).
9. The plants are heterosporous i.e. producing microspores or pollen grains and megaspores or embryo sacs.
10. Fertilization is single and development of embryo is partial because only $\frac{1}{4}^{th}$ of oospore is concerned with the development of embryo.
11. Polyembryony (the production of many embryos simultaneously) is of common occurrence but finally a single embryo matures.
12. The number of cotyledons in the seed is variable from one to many.
13. There is a clear alternation of sporophytic and gametophytic generation.
14. The significant character showing advancement over the pteridophytes is the permanent retention of the megaspore in the megasporangium fertilization and development of embryo inside it. This feature has given rise to seed habit.

a. Main groups of Gymnosperms:

The two main groups of the living gymnosperms are the cycads and the conifers or cone bearing trees. The cycads are tropical and sub tropical plants showing many fern like characters. Examples are *Cycas circinalis* and *C.revoluta*.

The conifers constitute the largest and most important group of gymnosperms. They are mainly the natives of temperate regions, well represented in the hills where they form big forests. The conifers of Pakistan include Pines, Firs, Cedars, spruce etc.

b. Uses of Gymnosperms

1. They are the best source of timbers used in building constructions.
2. They are the best wood source utilized in the construction of boats, railway lines etc. example *Cedrus deodara* etc.
3. They are the sources of resins. Example chir pine (*Pinus roxburgii*).
4. They are the best source as food item. Example chilghoza pine (*Pinus gerardiana*).

Fig: 8.18 Chilghoza pine nuts

5. Leaves of *Taxus baccata* are used in the synthesis of compounds called taxols, which are used in the treatment of breast cancer.

8.4.3 Class 3: Angiospermae

Angiosperms (Greeks: angio = sac, sperma = seeds) form one of the most highly evolved group of spermatophyta (seed plants). As the name shows the seed of angiosperms are enclosed in the fruits. They are flowering plants. The most successful and important of these plants belong to grass family which have colonized great areas of the earth surface in practically all sort of soil and climatic conditions. They constitute the main source of man's food supply.

a. Differences between monocots and dicots

Class Angiosperm are further divided into 2 sub-classes i.e monocotyledonous and dicotyledonous. Following are the differences between monocot and dicot.

1. In dicotyledons, the embryo bears two cotyledons: whereas in monocotyledons, it bears only one.
2. In the dicotyledonous embryo, the plumule is terminal and the two cotyledons lateral; but in the monocotyledonous embryo, the plumule is lateral and the cotyledon terminal. This is, however, not true in all cases.
3. In dicotyledons, the primary root persists and gives rise to the tap root; while in monocotyledons, the primary root soon perishes and is replaced by a group of adventitious roots.

4. As a rule venation is reticulate in dicotyledons, and parallel in monocotyledons. Among monocotyledons, *sarsaparilla*, *Smilax* and yams (*Dioscorea*), however, show reticulate venation and among dicotyledons, Alexandrian laurel (*Calophyllum*) shows parallel venation.

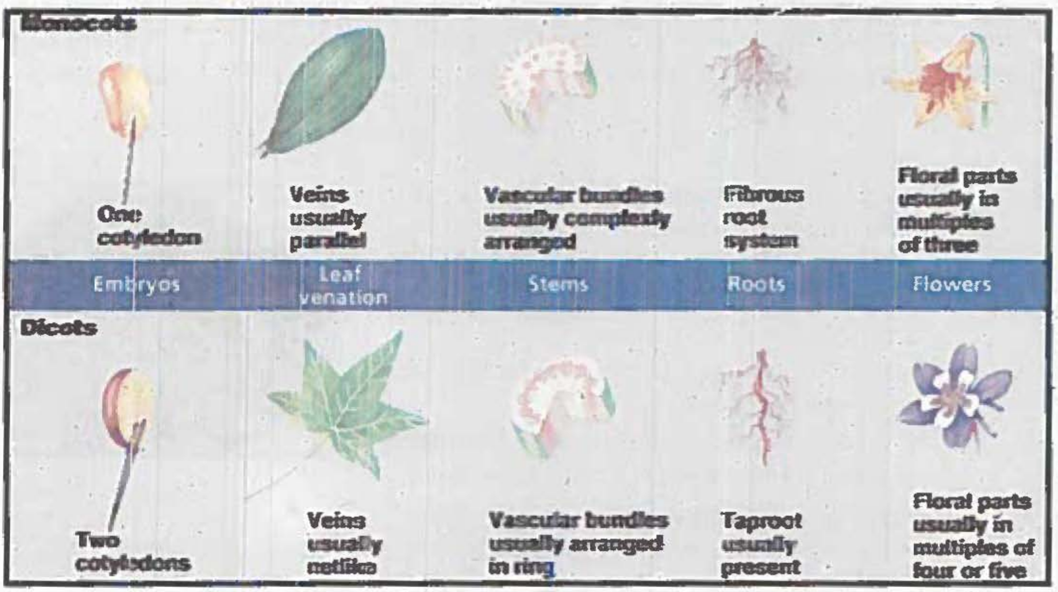


Fig: 8.19 Differences between monocot and dicot plants

5. The dicotyledonous flower has commonly a pentamerous symmetry; while the monocotyledonous has trimerous symmetry.

6. In the dicotyledonous stem, the vascular bundles are arranged in a ring and they are collateral and open. In the monocotyledonous stem, the bundles are scattered in the ground tissue and they are collateral and closed. Also the bundles are more numerous in monocotyledons than in dicotyledons. Further, the bundles are more or less oval in monocotyledons and wedge-shaped in dicotyledons.

7. In the dicotyledonous root, the number of xylem bundles varies from 2 to 6, seldom more, but in the monocotyledonous root, these are numerous, seldom a limited number (5 to 8).

8. Cambium soon makes its appearance in the dicotyledonous root as a secondary meristem and gives rise to the secondary growth, but in the monocotyledonous root cambium is altogether absent, and hence there is no secondary growth.

8.4.4 Life Cycle of Angiosperms

The angiospermic plant is a diploid sporophyte which is composed of root, stem, leaves and flowers. Flower is the reproductive organ, while stamens and the carpels are its reproductive parts. Stamens are male reproductive parts while the carpels are the female reproductive parts. Each stamen consists of an anther with four pollen sacs. A large number of microspores are produced by meiosis in each pollen sac. The wall of microspore becomes thick and is known as pollen grain.

During pollination the pollen grains are transferred to the stigma of the carpels. The pollen grain germinates and develops into male gametophyte or microgametophyte. The nucleus of the pollen grain divides into a generative nucleus and vegetative or tube nucleus. The generative nucleus divides into two male gametes. The pollen grain sends down a tube called the pollen tube which contains two male gametes and tube nucleus. The pollen tube together with the two male gametes and a tube nucleus constitutes the male gametophyte.

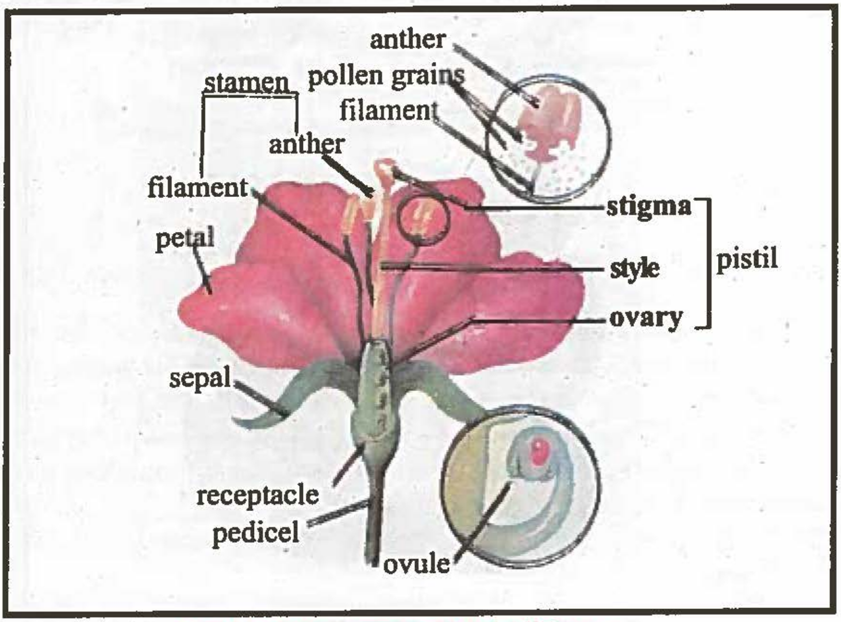


Fig: 8. 20 Structure of a typical flower

The carpel consists of a basal swollen part, the ovary, which contains one or many ovules. The ovule consists of a tissue called nucellus, which is covered by the integument. Certain changes occur in the ovule, leading to the formation of megaspore. The megaspore generally develops into seven celled female gametophyte or embryo sac. One of these seven cells is the egg or oosphere, one as endosperm mother cell (diploid in nature), two synergid cells and three antipodal cells.

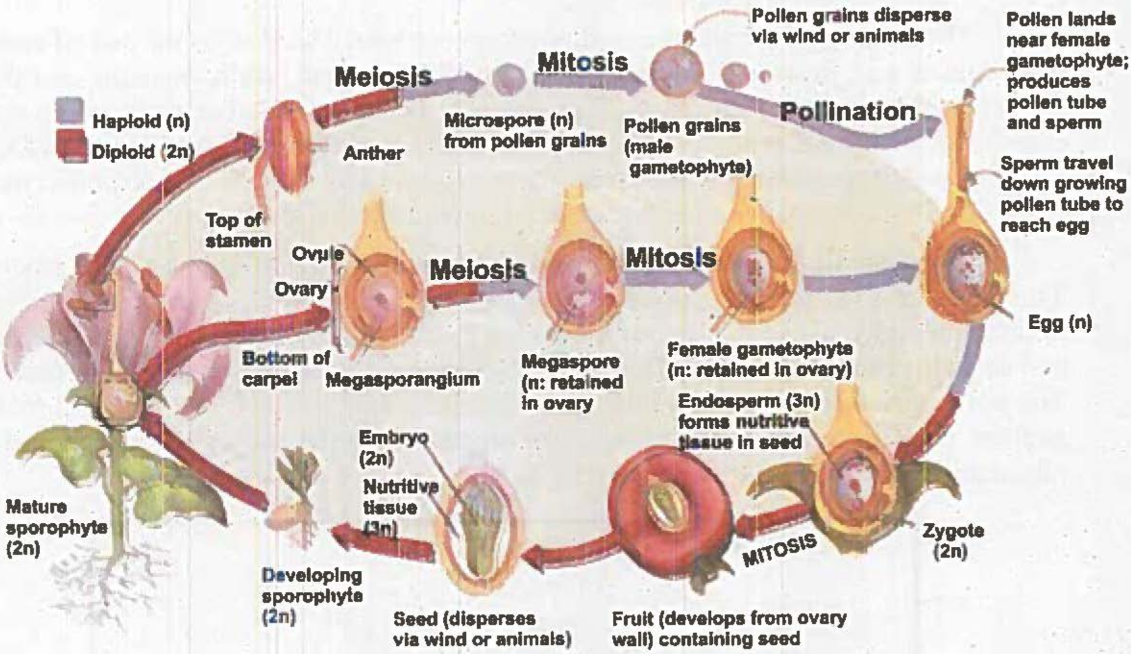


Fig: 8.21 Life cycle of an angiospermic plant.

The pollen tube enters the female gametophyte. The tip of the pollen tube ruptures and the two sperms are released into the female gametophyte. One sperm fuses with the egg to form zygote or oospore and the other sperm fuses with the endosperm mother cell to form fusion nucleus. The fusion of one sperm with the egg to form zygote and that of the other with the endosperm mother cell to form fusion nucleus is called **double fertilization**, which occurs only in the angiosperms.

The oospore develops into an embryo which consists of a radical, hypocotyle, plumule and one or two cotyledons.

The fusion nucleus develops into a nutritive tissue called endosperm. After fertilization in ovule matures into seed. The integuments of the ovule form the seed coats called testa and tegmen. The walls of the ovary develops into fruit on ripening. Under favourable conditions, the seed germinates to produce seedling which on development becomes sporophyte. The two kinds of generation i.e. gametophyte and sporophyte, one after the other show alternation of generation.

Angiosperms are successful because they can adapt themselves to almost all kinds of environments. Moreover they produce flowers, fruits and seeds which show

various adaptations for dispersal over large areas. Double fertilization is of common occurrence. They range in size from 1mm up to 100 m (Wolfia = 1mm, Eucalyptus = 100 m). They posses broad leaves and may be annual, biennial or perennial.

c. Inflorescence and its major types

In some angiosperms individual flowers are quite large and are borne singly on the pedicel. Such flowers are termed as solitary flowers. In most angiosperms the flowers are small and occur in groups. Such cluster of flowers arranged on the floral axis is called an inflorescence. Cluster of flowers in some way ensures pollination, fertilization and thus the reproductive success of the species.

The inflorescence may be racemose or cymose. In a racemose inflorescence the main axis continue to grow indefinitely until the last flower is formed at its apex. The oldest flowers are toward the base of the inflorescence and the youngest ones toward the apex. In a cymose inflorescence the main axis soon ends in a flower. One, two or more lateral branches develop below the terminal flower, each ending in a flower like the main axis. In this case the terminal flower is the oldest and the lateral flowers are younger.

Chief types of racemose inflorescence are:

1. Typical Raceme

In a typical raceme the main axis is elongated and bears laterally a number of flowers. Each flower has a pedicel or stalk e.g. *Cassia fistula* (amaltas)

2. The spike

The spike is a racemose inflorescence in which the main axis is elongated like raceme but the flowers are sessile i.e. without stalk e.g. *Achyranthus* (puth kanda) and bottle brush.

3. Catkin

It is a spike that usually bears only pistillate or staminate flowers. Examples are mulberry and willow.

4. Corymb

In this case the main axis is comparatively short and the stalks of the lower flowers are longer than those of the upper younger ones. As a result, all the flowers lie at about the same level e.g. *Iberis* (candytuft).

5. Umbel

In umbel the main axis is shortened. Flowers are stalked. Due to shortening of main axis, the flowers appear to arise at one level e.g. *Hydrocotyl* (brahmi booti). In some cases a number of umbels are present on the tip of the main axis. Such a compound inflorescence is called umbel of umbels or compound umbel e.g. carrot.

6. Panicle

A branched raceme is called panicle e.g. grapes, mango and oat.

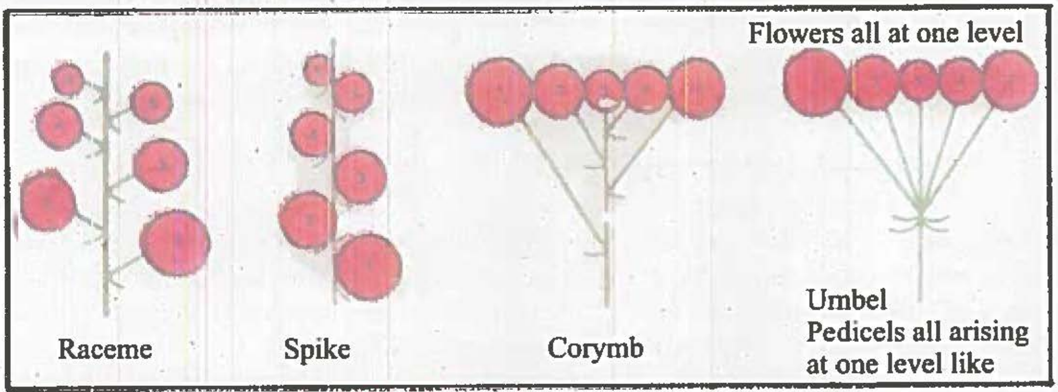


Fig: 8.22 (a) Types of inflorescence

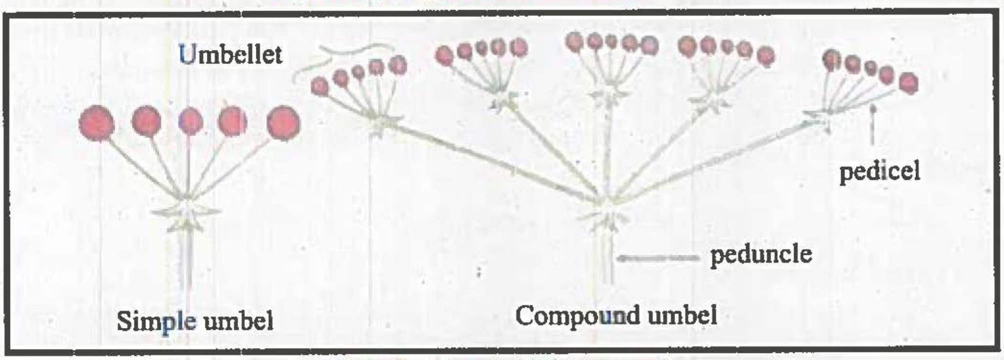


Fig. 8.22 (b) Types of inflorescence

7. Capitulum

In capitulum or head, the flowers are sessile and are crowded together on a very short axis. It looks like a single flower e.g. sunflower.

Chief types of cymose inflorescence are:

1. Uniparous Cyme (Monochasial Cyme)

In this case the main axis ends in a flower below which it produces one daughter axis only. The daughter axis as well as each succeeding one again end in flower and gives rise to one daughter axis only e.g. *Begonia*, *Tradescantia*.

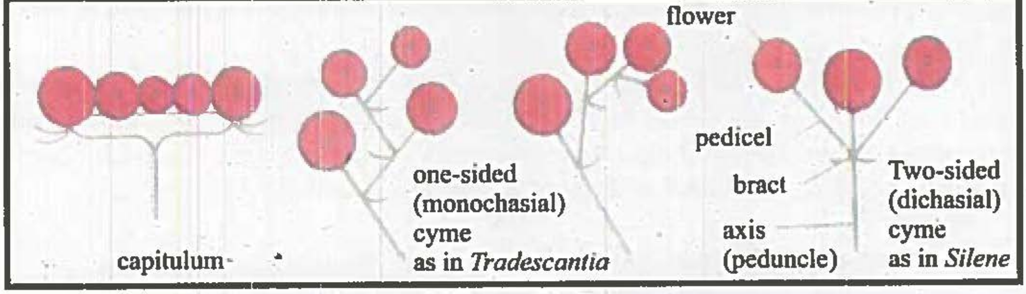


Fig: 8.22 (c) Types of inflorescence

2. Biparous Cyme (Dichasial Cyme)

In biparous cyme the main axis ends in a flower and produces two daughter axis. Each of the two daughter axis again ends in a flower and produces two daughter axis which may continue the branching in the same manner e.g. *Silene, Ipomoea.*

3. Multiparous Cyme

In multiparous cyme the main axis ends in a flower and produces three or more daughter axis each of which continues the branching in the similar manner e.g. *Euphorbia.*

d. Benefits of Angiosperms for Humans

Angiosperms contribute huge quantities of food and of great variety, e.g. cereals such as corn, wheat, barley, rye, rice; legumes like beans, peanuts, soybeans; fruits, vegetables and nuts, etc., Besides food, they also supply fibres such as cotton, limen (flax), jute, Indian hemp, Manila hemp, Sisal hemp, etc.,which are used in the manufacture of rope, string nets and bags. The most important of these fibres are the cotton fibres, used in the manufacture of clothing. Uses of plants in various industries and as medicines contribute to the well-being of mankind. Various articles of daily use and of economic importance are obtained from the flowering plants. Some of these, such as wood for building and furniture, fats and oils, fibres, cereals, fruits, sugar, drugs, (e.g. quinine, digitailin, morphine, cocaine, etc.), dyes (indjgo, haematoxylon, saffranin, chlorophyll, etc.), tea, coffee, spices, tobacco, paper, tannins, resins, gums, essential oils, rubber, fuel, alcohol, etc. Green flowering plants are also responsible for purifying the atmosphere as they absorb carbon dioxide and give out oxygen during photosynthesis.

One of the important aspect of angiosperms is their medicinal nature. Some of the more prominent plants in this regard are discussed below:

1. Cannabis (*Cannabis sativa*)

Used medicinally for thousands of years, today it is used in the treatment of sleeping disorders, autoimmune diseases and glaucoma.

2. Coca (*Erythroxylon coca*)

Cocaine was widely used as a local anaesthetic in the 19th century and coca leaf tea is taken for altitude sickness in South America.

3. Daffodil (*Narcissus spp.*)

Galantamine hydrobromide, a compound derived from daffodil bulbs, is being used to treat Alzheimer's disease.

4. Deadly nightshade (*Atropa belladonna*)

All parts of this plant, especially the berries, contain the extremely toxic chemical atropine. Atropine is used to relax the muscles of the eye and to stop muscular spasms.

5. Fever tree (*Cinchona succiruba*)

A native of Latin America, the bark of the fever tree produces quinine, which is used to treat malaria.

8.5 Vascular plants as successful land plants

Angiosperms form one of the most highly evolved sub-classes of Spermatophyta (Seed plants), the other being gymnosperms. The spermatophyta have been recently estimated to include about 300 families, 12500 genera and 300000 already known species. New species are being added each year by the exended survey of the vegetation of the earth and by a more critical examination of the older materials. Evidently, the angiosperms constitute a rapidly expending group which dominates the world of plants today.

To this vast assemblage of flowering plants must also be added thousands of new varieties, races or strains, etc. which owe their origin as also their perpetuation to man and to the care be bestowed upon them on account of their economic or commercial importance. The most successful and important of these plants belong to Gramineae or the grass family with 7500 species, which have colonized great areas of the earth surface in practically all sorts of soil and climatic conditions and constitute the main source of man's food supply.

The factors responsible for the success of angiosperms are;

1. Their adaptability to all kinds of environments.
2. The production of flowers, fruits and seeds which show various adaptations for dispersal over large areas.

The conifers (gymnosperms) and other vascular plants (Pteridophytes) though widely distributed are, however, not found to flourish in such diverse habitats as do the angiosperms.

DO YOU KNOW?

Deodar or Himalayan Cedar *(Cedrus deodara)* is the National tree of Pakistan.

KEY POINTS

- The fossil records of different organisms show the time period on the geological time scale when they were present abundantly on earth
- Phyletic lineage provides a link between the present day organisms with their remote past ancestors.
- In plants such as mosses and liverworts, the gametophytic generation is larger, dominant and autotrophic due to the presence of chlorophyll, while the sporophytic generation is smaller, less complex and heterotrophic, being partially or totally dependent upon the gametophyte.
- Bryophytes are the first plants which migrated to land. Bryophytes comprise the small and simplest non flowering land plants which usually occur in moist shady places.
- Bryophytes had invaded the land from water and therefore, they are called the first invaders of land among the plants.
- Tracheophytes have cells called tracheids which are water - conducting cells of xylem.
- The phylum tracheophyta is further divided into the Sub - Phylum: Psilopsida, Lycopsida, Sphenopsida and Pteropsida.
- Microphyllous leaf is with a single vein and megaphyllous leaf is with many veins.
- Psilopsida, a group of seedless vascular plants have evolutionary importance as they represent connecting link between bryophytes and pteridophytes.
- Seed may be defined as a ripened and fertilized ovule.
- In most angiosperms the flowers are small and occur in groups. Such cluster of flowers arranged on the floral axis is called an inflorescence.
- Angiosperms constitute a rapidly expanding group which dominates the world of plants today.

EXERCISE

A. Choose the correct options from each statement and encircle it.

1. In bryophytes the male reproductive organ is known as:

a.	Stamen	b.	Antheridium
c.	Carpel	d.	Archegonium

2. The plants in which the seeds are enclosed in the fruit are:

a.	Gymnosperms	b.	Angiosperms
c.	Bryophytes	d.	Tracheophytes

3. The flower in which both the male and female reproductive parts are present is termed as:

a.	Staminate	b.	Pistilate
c.	Hermaphrodite	d.	Heterogamous

4. The microspore produced in the microsporangia germinates to form:

a.	Male gametophytes	b.	Female gametophytes
c.	Sporophyte	d.	Embryophyte

5. Gymnosperm is characterized by:

a.	Having fruits	b.	Having seeds
c.	Lacking ovaries	d.	Having vessels

6. Male gametophyte of angiosperm is represented by:

a.	Pollen grain	b.	Anther
c.	Microsporangium	d.	Pollen mother cell

7. Which one of the following is triploid structure?

a.	Integuments	b.	Pollen grain
c.	Antipodals	d.	Endosperm

8. Embryo sac is termed as

a.	Megasporangium	b.	Megaspore
c.	Female gametophyte	d.	Female gamete

9. The plants which have naked seeds belong to the group:

a.	Tracheophytes	b.	Gymnosperms
c.	Angiosperms	d.	Pteridophytes

10. Double fertilization is the characteristic feature of only the:

a.	Angiosperms	b.	Gymnosperms
c.	Pteridophytes	d.	Bryophytes

EXERCISE

11. The inflorescence of mulberry and willow is called
    a. Catkin   b. Corymb
    c. Umbel   d. Panicle
12. The female gametophyte of the flowering plants is also known as the
    a. Ovule   b. Endosperm
    c. Embryo sac   d. Placenta
13. Which of the following characteristics differentiates pteridophytes from gymnosperms?
    a. Production of seeds   b. Formation of archegonia
    c. Production of pollen tube   d. Alternation of generation
14. The liverwort and mosses belong to which group of plants?
    a. Thallaphytes   b. Bryophytes
    c. Pteridophytes   d. Gymnosperms
15. The Tracheophytes include which of the following groups of plants?
    a. Thallophytes and Bryophytes
    b. Bryophytes and Pteridophytes
    c. Pteriodophytes and Spermatophytes
    d. Thallaphytes and Spermatophytes
16. Which one of the following vascular plants is said to be a living tossil?
    a. Rhynia   b. Psilotum
    c. Selaginella   d. Equisetum
17. Mycorrhiza is a common feature of the sporophytes of:
    a. Psilotum   b. Selaginella
    c. Pinus   d. Rhynia
18. The most highly evolved plants are the:
    a. Angiosperms   b. Gymnosperms
    c. Bryophytes   d. Pteridophytes
19. Catkin type of inflorescence is found in:
    a. Mulberry   b. Grapes
    c. Candytuft   d. Euphorbia

B. Write answers to the following short questions.

1. Define alternation of generation and give its importance.
2. What is the role of heterospory in the evolution of seed?
3. Differentiate between an antheridium and an archegonium.
4. Give two differences between bryophytes and tracheophytes.
5. Write three examples of sub phylum psilopsida.
6. Write four differences between angiosperms and gymnosperms.
7. What is the difference between microphyllous leaf and megapollylous leaf?

EXERCISE

C. Answer the following questions in detail.

1. Describe the adaptations shown by bryophytes to land life.
2. Explain the life cycle of flowering plant.
3. Write detailed note on any two of the following.
   a. Psilopsida
   b. Sphenopsida
   c. Lycopsida
4. Give important characters of liverworts and hornworts.

Projects

- Teacher may plan a trip to nearby area with natural vegetation and ask his/her students to collect plants in the following manner.

1. Two examples of bryophytes.
2. Two examples of fern.
3. Five examples of angiospermic plants.
4. Three examples of gymnosperms

Take guidance from the teacher for proper preservation of plants.

- Make a medicinal plant collection present in your local environment. Paste them on cards and write their taxonomic classification for every collected plant. Take guidance from your teacher for identification and classification of your plant collection.

Chapter 9

Diversity Among Animals

At the end of this chapter students will be able to:

- Describe the general characteristics of animals.
- Classify animals on the base of presence and absence of tissues.
- Differentiate the diploblastic and triploblastic levels of organization.
- Describe the types of symmetry found in animals.
- Differentiate pseduocoelomates, acoelomates and coelomates.
- Classify coelomates into protostomes and deuterostomes.
- Describe the general characteristics, importance and examples of sponges, cnidarians, platyhelminths, aschelminths (nematodes), mollusks, annelids, arthropods and echinoderms.
- Describe the evolutionary adaptations in the concerned phyla for digestion, gas exchange, transport, excretion, and coordination.
- Describe the characteristics of invertebrate, chordates and vertebrates.
- List the diagnostic characteristics of jawless fishes, cartilaginous fishes and bony fishes.
- Describe the general characteristics of amphibians, reptiles, birds and mammals.
- Differentiate among monotremes, marsupials, and placentals.
- Describe the evolutionary adaptations in concerned groups for gas exchange, transport and coordination.

Introduction

Kingdom Animalia include all the animals found in this world. The word Animalia is derived from the Latin (anima means soul or breath). All those animals in which the outer most covering of the cells is a "cell membrane" (not a hard cell wall) are classified as member of kingdom Animalia. According to the recent reports kingdom Animalia is comprised of more than half a million species of animals. Some important characteristics of animals can be described as follows:

- Animals develop from two dissimilar, haploid gametes i.e. a larger egg and a smaller sperm.
- The outer most covering of all their cells is a cell membrane.
- They have a multicellular body.
- They are made of diploid eukaryotic cells.
- Animals are heterotrophic and they ingest their food.

Evolutionists believe that animals have been evolved from the single celled organisms included in kingdom Protoctista, but it has yet to be decided that from which group of protoctists, they have evolved. Their ancestry is still a topic of hot debate among the biologists.

9.1 Classification of Animals

Being a very diverse group, animals need to be classified for the convenience of study. In ancient times when the knowledge of cells and facility of microscopic studies were not available, scientists roughly divided the animals into two groups on the basis of presence or absence of the vertebral column.

a. Vertebrata: This group includes all those animals which possess a back bone or vertebral column. Vertebrata included fishes, amphibian, reptiles, birds and mammals.

b. Invertebrata: All those animals which do not possess backbone were included in this group. Invertebrata was divided into following phyla.

1. Phylum Porifera
2. Phylum Coelenterata
3. Phylum Platyhelminths
4. Phylum Aschelminths
5. Phylum Annelida
6. Phylum Mollusca
7. Phylum Arthropoda
8. Phylum Echinodermata
9. Phylum Chordata (excluding subphylum vertebrata)

Few invertebrate animals which do not fit to any of the above mentioned phyla

are classified into "phylum ctenophora" and "minor phyla" but the number of animals and their species present in these phyla are so much less that they are generally ignored. They are inhabitants of deep seas and we know very little about them.

Animals have also been classified on the basis of the cellular composition of their body into following three groups.

1. **Protozoa :**

Animals have a single celled body which performs all the vital functions of the life e.g. amoeba, paramecium, plasmodium, tryponsoma etc. (In recent classification protozoa has been treated as a separate kingdom Protista).

2. **Parazoa:**

These are simple multicellular animals believed to evolve from protozoa. They are just collection of cells which are not differentiated into tissues and organs. For example, porifera.

3. **Metazoa:** Animals of this group are composed of many cells. The cells are arranged into tissues, organs and organ systems. This group includes all other phyla from coelenterates to chordates. for example, metazoa are kept in a subkingdom Eumetazoa.

Another way of classifying animals is on the basis of arrangement of their cells in to layers. In this classification all those animals in which body cells are arranged into two layers ectoderm and endoderm are called **diploblastic**. Names of these two layers are the ectoderm and the endoderm. The only diploblastic animals are coelentrates. The animals in which the body is composed of three layers of cells i.e. ectoderm, mesoderm and endoderm are called **triploblastic.** All the phyla from platyhelminthes to chordates are included in this group.

9.2 Complexity in Animals

Eumetazoa are classified into two groups on the basis of symmetry of the body. Those having a radial symmetry are included in grade **Radiata.** Their body can be divided in to equal parts in more than one plane. These animals are diploblastic. Animals of phylum coelenterata (cnidaria) are included in this group.

Animals with a bilateral symmetry are included in to grade **Bilateria.** Body of these animals can be cut into two identical halves only in one plane that is they have a right and left side of the body. They mostly posses a distinct anterior end. In majority of the bilateria the anterior end possess a head, in which nervous tissues are concentrated and opening of digestive tube is located. Among the phyla described previously, platyhelminthes, nematode, annelida, mollusca, arthropoda, and chordata are all included in this group. All the animals in grade Bilateria are triploblastic.

9.2.1 Diploblastic and Triploblastic Organization

Animals in which the body is composed of two layers of cells are called diploblastic animals. In between these two layers a jelly like non-cellular material

present called mesogloea. Although they have developed some organs but they show lesser degree of specialization, hence the organ system is not well developed. They do not posses any transport system and the nervous system is in the form of a network of neurons without any central control (brain). Their body contains a central cavity called coelenteron or gastro-vascular cavity. The anterior end of this cavity is mouth, through which water and food enters. As they do not posses any anus that is why the undigested food is also excreted through the same opening. This type of digestive system is called as sac like digestive system. They reproduce both asexually and sexually.

In triploblastic animals the body is composed of three layers of cells called ectoderm, mesoderm and endoderm. In triploblastic animals the cells show greater degree of specialization in to organs and organ systems. Their digestive system is tube like and most of them have a separate opening for taking food and excretion of undigested wastes respectively.

The ectoderm forms skin (integumentary system) and nervous system. The endoderm forms the lining of the digestive tract and associated glands. Rest of the organs are formed by the mesoderm like muscular, reproductive, excretory and skeletal systems etc. Triploblastic animals may be classified into acoelomates, pseudoceolomates and coelomates.

a. Acoelomates are those animals which do not possess a body cavity or coelom. In these animals instead of forming parietal and visceral layer the mesoderm forms a loose, cellular tissue which fills the space between epidermis and gastrodermis. This loose tissue is called mesenchyma or parenchyma. Function of mesenchyma is to support and protect the internal organs by filling the spaces between them like a packing material.

Acoelomates do not have much developed body systems. Only excretory and nervous systems are developed to certain extent. Animals of phylum platyhelminthes are classified as acoelomates.

b. Pseudocoelomates: These are the animals which although possess a fluid filled body cavity, but it is not a true body cavity formed between the layers of mesoderm. It rather develops from blastocoel and not from the archenteron of gastrula. Pseudocoelom is not lined by coelomic epithelium. It is rather lined externally with a muscular layer and internally with the cuticle of intestine. Pseudocoelom has no relation with reproductive and excretory systems. Animals of phylum Aschelminthes are included in this group.

tidbit

Animals of phylum echinodermata are bilaterally symmetrical in their larval stages but the adults gain a radial symmetry secondarily due to their special mode of life.

c. **Coelomates** are the animals having a true body cavity or coelom. The cavity is filled with coelomic fluid. All the animals from phylum annelida to phylum chordata are coelomates. Coelomates are classified as Protostomes and deutrostomes.

Protostomes (mollusks, annelids, and arthropods) develop so that the first opening in the embryo is the mouth (protostome = first mouth). Protostomes are bilaterally symmetrical, have three germ layers, the organ level of organization, the tube-within-a-tube body plan, and a true coelom. **Deuterostomes** (as exemplified by the echinoderms and chordates) develop the anus first, then the mouth at the other end of the embryo. Deuterostomes are coelomate animals having the following embryological characteristics:

- Radial cleavage in embryonic cell division: the daughter cells lie on top of

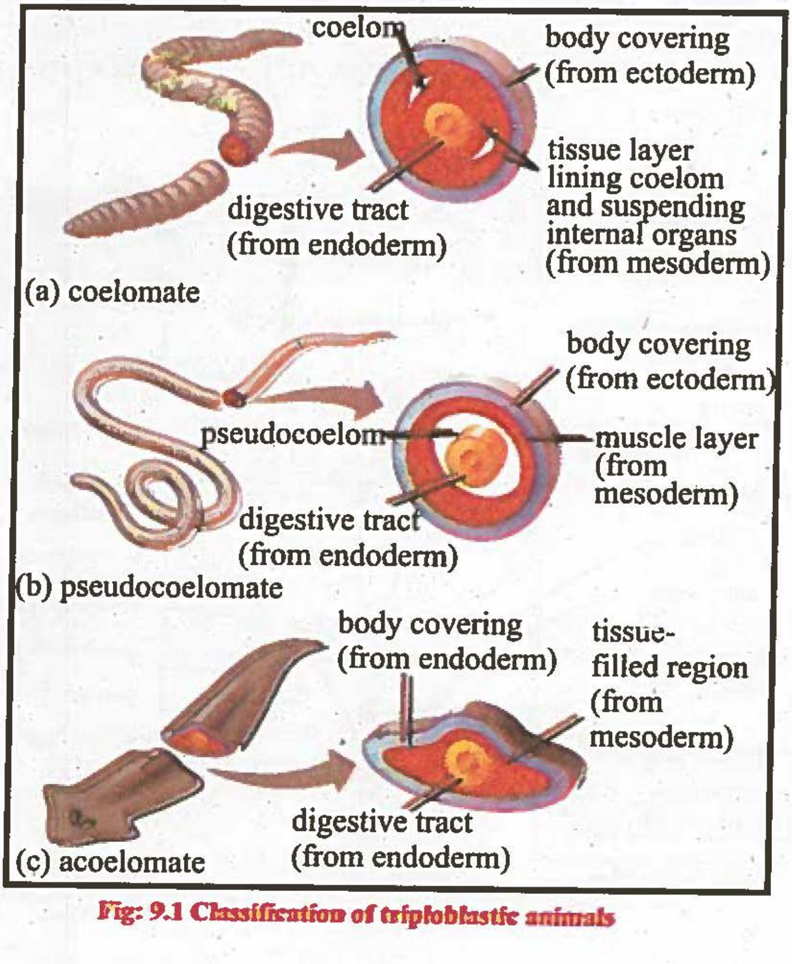


Fig: 9.1 Classification of triploblastic animals

previous cells.

- Fate of cells is indeterminate; if embryonic cells are separated, each one develops into a complete organism.
- The blastopore is associated with the anus, and the second embryonic opening .is associated with the mouth

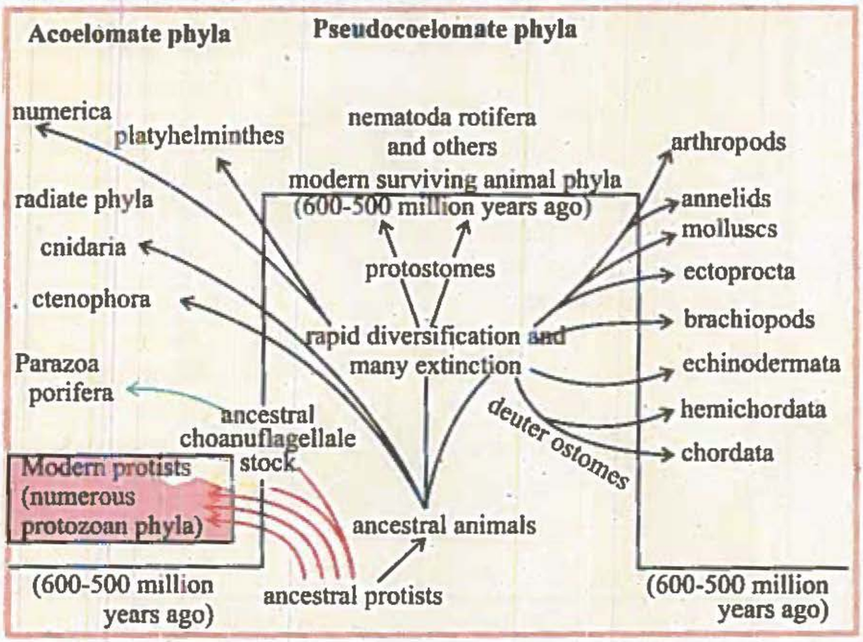
9.3 Subkingdom Parazoa

The only phylum included in this subkingdom is Phylum porifera

9.3.1 Phylum Porifera

Word porifera is derived from Latin; Porus means minute holes or tiny openings and ferra means to bear. Hence animals of this phylum bear small holes or pores all over the body. These pores are called **ostia.** Their bodies are made of groups of cells but the tissues and organs are not present. They are the most primitive metazoans and are commonly called as **sponges**. All the members of this phylum are aquatic mostly marine.

Interpreting and Communication
Evolutionary tree of various animal phyla



The ostia are part of canal system in which water circulates and brings food to the body. This food is digested inside body cell (intracellular digestion) as well as in the spongeocoel (extracellular digestion).

Food of porifera includes phytoplanktons, zooplanktons, protozoans, crustacea and other small organisms but the major part (80 %) of the food is comprised of dead decaying organic matter. Sponges are sessile (stationary) and do not contain any locomotary organ. Their dispersal takes place during asexual reproduction by budding and gemmule formation or by sexual reproduction through the formation of eggs and sperms. Process of excretion takes place by diffusion.

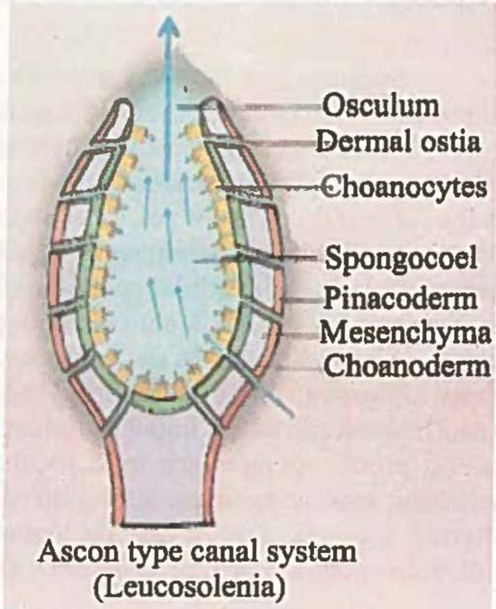


Fig: 9.2 T.S of sponge body to show canal system

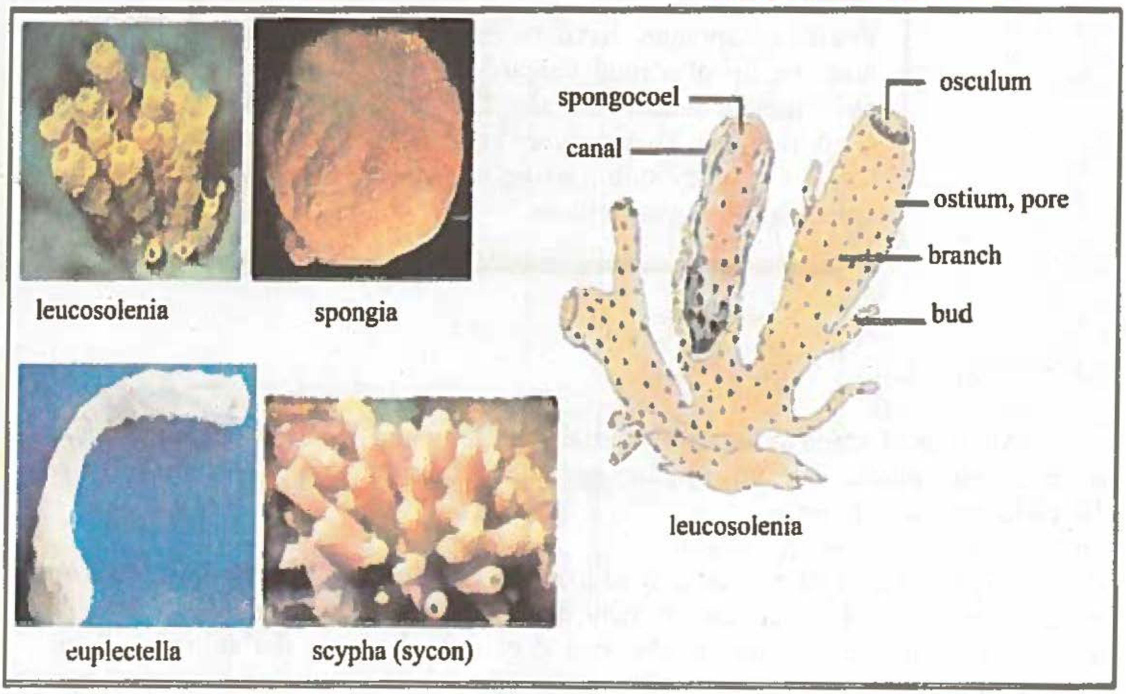


Fig: 9.3 Sponges

Sponges also lack any nervous system. Neurosensory cells and neurons are found which are believed to coordinate the flow of water.

All sponges except class mykospongida have skeleton. The skeleton consist of carbonate of lime or silicon in the form of spicules or of spongin (a fibrous protein) in the form of fibers. Sponges are economically important animals as they are used for washing and bathing by human beings from ancient times. Even after the production and availability of artificial sponges, still natural sponges have their demand in the market and they make a considerable proportion of the total business all over the world. Sponges found in the warm waters of Mediterranean Sea are commercially more important. Sponges are used in surgical operations because of their ability to absorb blood and other fluids. To reduce the noise pollution and to make the buildings sound proof, sponges are used to absorb sound waves. Examples are sycon (a common marine sponge), spongilla (a freshwater sponge) leucoselenia (a tubular marine sponge), Euplectella or Venus flower basket (a very beautiful, delicate, siliceous sponge appear to be made of glass framework) etc.

Tidbit

Predatory sponges have recently been discovered near the lip of a mud volcano in Barbados trench. 5000 meters beneath the sea. They belong to family Cladorhizidae. They are very large, about the size of a large dog. They stab passing crustaceans with their spicules and consume them.

9.4 Subkingdom Eumetazoa

a. Grade Radiata

Animals of grade radiata have radial symmetry and can be divided into equal halves in many planes. The only phylum included in this grade is phylum coelenterata also called phylum cnidaria.

I. Phylum Coelenterata (Cnidaria)

The word coelenterata is derived from Greek: Kolios means Hollow, enteron means intestine, and hence the animals of this phylum have a hollow, sac like intestine. Phylum coelenterata is also called cnidaria because the animals of this group have certain specialized cells, cnidocytes which give rise to nematocyst (special stinging cells).

Coelenterates are exclusively aquatic; majority live in marine environment but some live in freshwater as well.

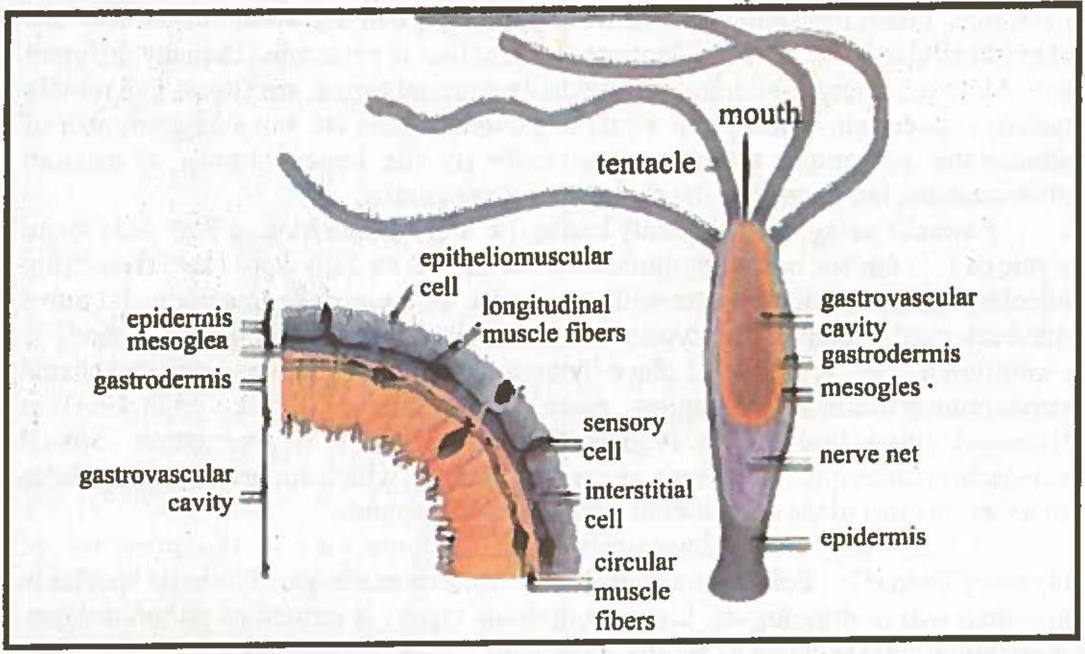


Fig: 9.4 T.S of Hydra

Coelenterates have a diploblastic organization in which the cells are arranged in to tissues and organs. The outer layer is ectoderm and the inner layer is endoderm. In between the two layers a jelly like, noncellular and nonliving material is present, called **mesogloea.** The ectodermal cells are not only protective in function but they also give rise to nematocyst. The cells of endoderm are specialized for digestion. They release digestive enzymes and also absorb the digested food. The only cavity in the body is **enteron or gastrovascular cavity** which is associated not only with digestion but also with many other functions of the body of animal. In coelenterates mouth is surrounded by number of tentacles which bears organs of offense and defense called **nematocyst.** As soon as an organism touches the tentacles the nematocysts are fired which movement of tentacles the animals is brought to the mouth. Inside the gastrovascular cavity, the food is digested by the action of the enzymes released by the glandular cells of endoderm, which digest the food and the remaining undigested material is again thrown out of the mouth. The digested material is absorbed into the cells of endoderm lining the enteron through diffusion and is also provided to the cells of ectoderm. In some coelentrates there are special feeding **zooides** which are called "gastrozoids" which perform only the function of nutrition for the whole colony. This

arrangement is found in Obelia and the animals of order siphonophora. Coelenterates are carnivorous. Their food varies according to their size from zooplanktons, crustaceans, insect larvae to small fishes. Both the type of digestion i.e. Intracellular and extracellular is found. In coelentrates locomotion is performed in many different ways. Although many coellentrates, especially colonial forms, are sessile and remain attached with certain object in the water e. g obelia, corals etc. but a large number of coelenterates can move actively. Coral reefs are the huge volumes of calcium carbonate in the sea formed by the skeleton of stony corals.

Physalia pelagica, commonly known as "Portuguese Man of War", can swim at a rate of 12.1 cm/sec by the rhythmic contraction waves. Jelly fishes are fast moving coelenterates. They release water with force from their umbrella like body and move in the backward direction. This type of locomotion is called Jet-propulsion method.

Respiration and excretion takes place by simple diffusion. Both asexual and sexual reproduction is found in coelentrates. Asexual reproduction is more common. It is performed either budding or regeneration or rarely by fragmentation. Sexual reproduction takes place by means of eggs and sperms which are produced in ovaries and testes. In most of the coelenterates, the sexes are separate.

A very important characteristic of coelenterates is the presence of **polymorphism** (Gr: Poly-many, morphe-Form). The existence of a single species in more than two morphological forms (individual types) is termed as polymorphism. These individual are called as **zooids**. Two major types of zooids are **Polyps** (tube like body) and **Medusae** (Umbrella like body). Another very important phenomenon found in coelenterates is **alternation of generation** or **metagenesis**. In this phenomenon asexual generation alternates sexual generation.

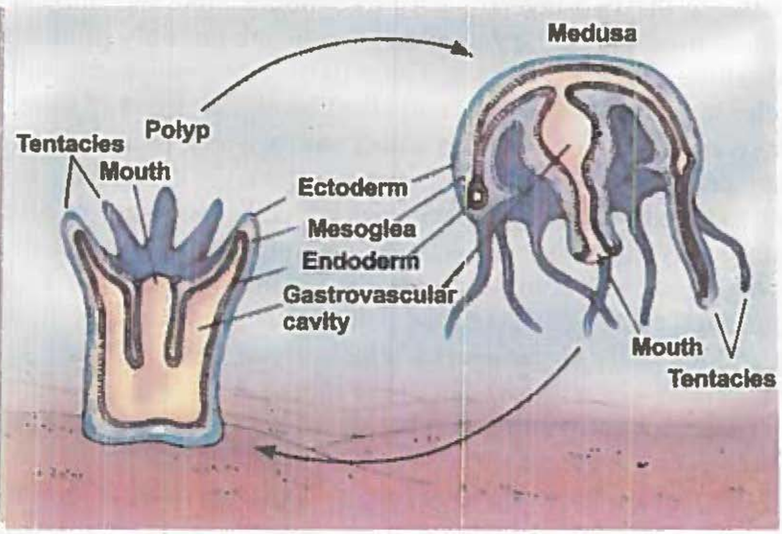


Fig: 9.5 Jelly Fish

For example in Obelia, the polyp form, called blastostyle reproduces in to saucer shaped medusae. These medusae develop gonads in which eggs or sperms are formed. The sperms fertilize the eggs and the planula larva is formed which grows into a new polyp. In this way the polyp produces a medusa and the medusa produces a polyp.

Some common example of this phylum are Hydra, Obelia, Jelly fish, sea anemone and Corals. Corals are economically very important as they form coral reefs. Jelly fishes are eaten as delicacy. Some of them are poisonous and cause serious health threat for divers and swimmers. Corals live in colonies and they make huge structures called coral reefs.

Fig: 9.6 Corals

Fig: 9.7 Sea anemone

b. Grade Bilateria

Animals included in this grade have bilateral symmetry. Body of these animals can be cut into two identical halves only in one plane that is they have a right and left side of the body. All the phyla from platyhelminthes to chordates are bilaterally symmetrical. They are all triploblastic as well.

1. Phylum Platyhelminthes

Body of all the animals included in this phylum is dorso-ventrally flattened, i.e. leaf like or paper like hence called flat worms. They are bilaterally symmetrical. They are the first triploblastic metazoa and are acoelomates. Their bodies are either unsegmented or superficially segmented, and true segmentation is absent. In free living form the ectoderm is ciliated but in parasitic forms the cilia are absent and a thick coat of cuticle is present for protection. Organs of attachment are present in the form of hooks or suckers. Digestive system in free living form is developed but in parasitic forms it is either poorly developed (Class Trematoda) or completely absent (Class Cestoda). No circulatory or respiratory system is present. Excretory system is with few flame cells (flame cell is a structure with thin elastic walls with a nucleus and a cavity containing many long cilia flickering like a flame) attached with ducts which open at excretory pore. Nervous system is with a pair of anterior cerebral ganglia and a

ventral ganglion connected by nerve ring and one or three nerve cords.

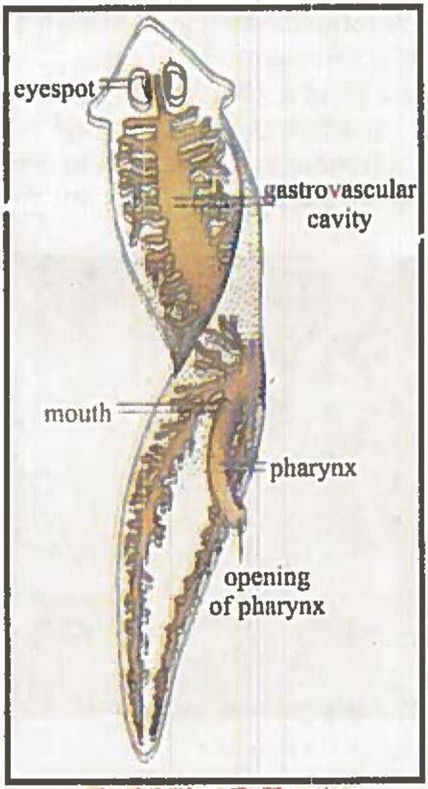


Fig: 9.8 Planaria showing digestive system

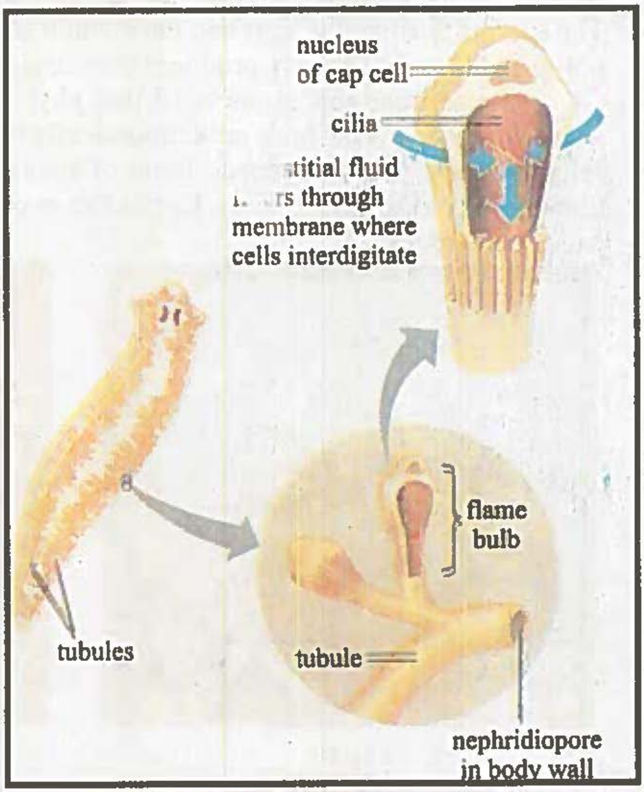


Fig: 9.9 Planaria showing excretory system

Muscular layer is well developed in free living forms which help in locomotion. They are hermaphrodite i.e. both sex organs are found in the same animal. Reproductive system is well developed with gonads, their ducts and copulatory organs. Eggs are small with yolk and are produced in very large number. Self and cross both types of fertilization is present among platyhelminthes. Fertilization is always internal. The fertilized eggs are passed out which either directly grow into a new individual as in planaria and tape worm or different type of larvae are formed as in liver fluke.

Regeneration ability is present in Class Turbellaria (Planaria) but Class Trematoda (liver flukes) and Class Cestoda (tape worms) being parasitic do not show any regeneration. All the members of this phylum are solitary i.e. not found in colonies.

In Cestods (Tapeworms) the digestive system is completely absent. Tape worm absorbs digested food from the wall of the intestine of the host where they remain attached with the help of scolex (head) which is provided with hooks and suckers.

Platyhelminthes is a diverse group with about 15000 species ranging in size from few millimeters (Planaria is about 10 mm) to many feet (tape worm reaches to 16 feet or about 5 meters). Economically they are very important. Liver flukes and tape worms cause serious diseases in sheep, goat, cow, buffalo, pigs, horse, donkey and other domesticated animals causing heavy mortality which inflicts great economic losses. Human tapeworm *Taenia saginata* is a serious health hazard in poor and developing countries of Asia and Africa. Its infection results in retarded growth, nausea, weight loss, abdominal pain and nervous disorders (resembling epilipsy) and in case of children death may also be caused.

Common examples of this phylum is Planaria (Dugesia), Liver fluke (*Fasciola hepatica*), Tape worm (*Taenia solium*) etc.

2. Phylum Aschelminths (Nematoda)

The word nematoda is of Greek origin which means thread. Nematodes are also called as round worms. In nematodes the body is long and cylindrical tapering at both ends. They are bilaterally symmetrical and are triploblastic. They are **pseudocoelomates** i.e. the body cavity is not a true coelom. The body is **non-segmented.**

Nematodes do not have any cilia on their body. A hard layer of cuticle is present on the body for protection. No respiratory or circulatory system is present. The fluid contained in the body cavity performs the function of the blood. The alimentary canal is well developed with an anterior opening (mouth) and posterior opening (anus).

The excretory system consists of two longitudinal canals on each side which open on the ventral side by a small excretory pore close behind the mouth. Nervous system consists of a nerve ring which encircles the pharynx and sends its branches in different parts of body.

In nematodes the muscles are arranged in four longitudinal bands. Circular muscles are not present in these worms. Therefore, they show specific type of whipping movements.

Sexes are generally separate. Males are smaller than females. Power of regeneration is absent.

In male the testes is a long, coiled thread with a seminal vesicle which posteriorly opens in to rectum by a short ejaculatory duct. Female reproductive organs are a pair of very much coiled ovaries passing into uterus and two uteri unite posteriorly forming vagina which on the ventral surface at the female genital aperture situated in the middle line.

The most common animal of this phylum is *Ascaris lumbricoides.* It is an endoparasite in the small intestine of man. It lives freely in the lumen (cavity of the small intestine). The body is elongated, cylindrical and tapering on both ends. Sexes

are separate. The female is 8-16 inches long but the male is 6-12 inches in length.

The anterior part of both male and female is similar that is pointed but the posterior part of the male ascaris is curved with two spine like structures called penial setae. In female the posterior end is not sharply pointed.

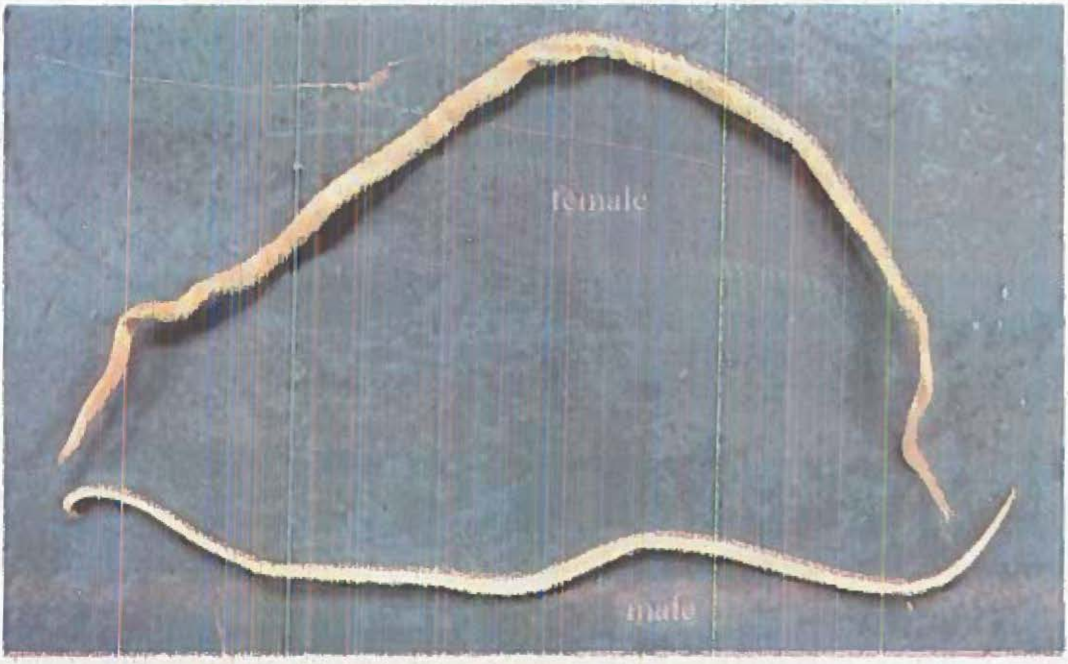


Fig: 9.10 Ascaris

Enterobius vermicularis is another human parasite commonly known as pinworm. It mostly parasitizes children which ingest its eggs with soil or in some other way. It lives in the caecum, colon and appendix of its host.

It causes severe itching of the anus, inflammation of the mucus membrane of colon and appendix. This results in sleeplessness (insomnia) and loss of appetite.

Nematodes are found every where in fresh and salt water, in soil etc. A lump of top soil may contain thousands of nematodes. Many of them are free living but some are parasitic on plants and animals including man.

These parasitic forms cause great economic losses in terms of expenditure in health sector and crop destruction. Free living soil nematodes decompose organic matter and play a major role in soil fertilization.

Nematodes are an important part of most food chains and food webs and are therefore economically very important.

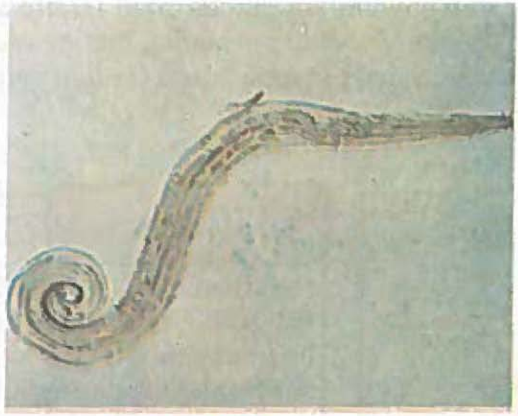


Fig: 9.11 Pinworm

3. Phylum Mollusca

Name of the phylum has been originated from a Latin word "molluscus" which means soft; hence animals in this phylum have soft bodies which are mostly protected by calcareous shells. This is the second largest phylum of invertebrates having more than 80,000 species (in addition 35,000 fossils forms are also reported). General characters of molluscs are following:

They are soft bodied, triploblastic animals possessing bilateral symmetry. They are coelomates. Most of them are protected by a shell of calcium carbonate ($CaCO_3$) secreted by the mantle. The shell may be in one piece or two pieces. In some molluscs the shell may be internal, reduced or totally absent. The body can be differentiated into a head, a dorsal visceral hump and a ventral muscular foot. The body is covered by a tough, fleshly membrane called mantle which also secrets shell.

The space between the body and mantle is called mantle cavity in which kidneys and anus open. They respire through gills present in mantle cavity. They have a rasping tongue called **radula**. The digestive system is well developed. The body cavity is a haemocoel. Blood vascular system consists of a single heart (with one ventricle and one or two auricles) arteries, veins and haemocoelic chambers.

The nervous system consists of three pairs of orange coloured ganglia connected by nerve cords. Nerves arise from these ganglia and enter different organs of the body. Sexes are generally separate. The testes are white and ovaries are of reddish colour. Fertilization is external. Development is either direct or a larva is formed called **Glochidium larva.**

Animals of this phylum are economically very important. They are mostly marine but many molluscs live in fresh water or even in terrestrial environment. Shells of molluscs are used as ornament and are also used to make decoration pieces. The pearl formed by the marine mussel is used in jewelry. Octopus and cuttle fish and large sized mussels are eaten as delicacy in many countries of the world.

Common examples of this phylum are garden snail (*Helix aspersa*), slug (*Limax maximus*), Freshwater mussel (*Anodonta grandis*), marine mussel (*Mytilus edulis*) oyster (*Ostrea lurida*) which makes pearl, squid (*Loligo pealii*), cuttle fish (*Sepia officinalis*) and octopus (*Octopus bairdi*).

Fig: 9.12 Glochidium larva

Tidbit

In certain molluscs like octopus and cuttle fish a blue coloured respiratory pigment **haemocyanin** is present. The blue colour of the pigment is due to the presence of a copper molecule (as iron in haemoglobin). Haemocyanin can transport three times more oxygen as compared to haemoglobin.

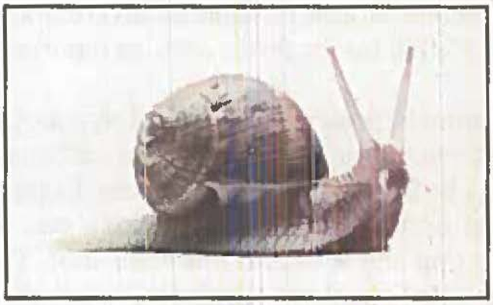


Fig: 9.13 a. Garden snail (*Helix aspersa*)

b. slug (*Limax maximus*)

Fig: 9.14 a. Oyster (*strea lurida*) b. Mussel (*Anodonta grandis*),

4. Phylum Annelida (First true Coelomates)

The word annelida is of Greek origin; annelus means little ring, the animals of this phylum have their bodies divided in to rings (segmented body) hence called annelids. Body of annelids is bilaterally symmetrical. The body may be cylindrical as in earthworm, or dorso-ventrally compressed as in neries. Body is **metamerically segmented** i.e. the organs are repeated in every segment. They are triploblastic. They are coelomates having a true **coelom** They have a closed circulatory system. In earthworm four to five pairs of hearts called **pseudo-hearts** are present, which contract rhythmically to keep the blood moving in the system. Colour of the blood is red due to haemoglobin dissolved in the plasma.

The digestive system is well developed especially in free living species. Different digestive organs are well formed. Excretory system consists of metamerically arranged **nephridia**. Nephridium opens to the exterior through **nephridiopore**. The body is covered with glandular epidermis, which secretes mucus and keeps the skin moist. Locomotary organs are **setae** (in earthworm) or **parapodia** (in neries). Respiration is through general surface but some annelids e.g. neries have **gills** under parapodia. The body is covered with cuticle.

Annelids are mostly **hermaphrodite** i.e. the same animal contains both type of sex organs; ovaries and testes but cross fertilization is common. **Trochophore larva** is formed during life cycle of some annelids especially in marine species. They are found everywhere in damp soil, fresh and marine water and some species are parasitic too.

In annelids like earthworm every segment of the body contains a blood vessels, epidermal structures (like setae etc.), nervous and excretory organs. This pattern is repeated in most of the segment with some variation.

Annelids are economically vèry important group of invertebrates. Earthworm makes the soil porous and fertile which increases the production of crops. Animals of this group are an integral part of the food chains both in aquatic and terrestrial environment. Leech being a parasite of cattle damages their health and growth. Common examples are *Pheritema posthuma*

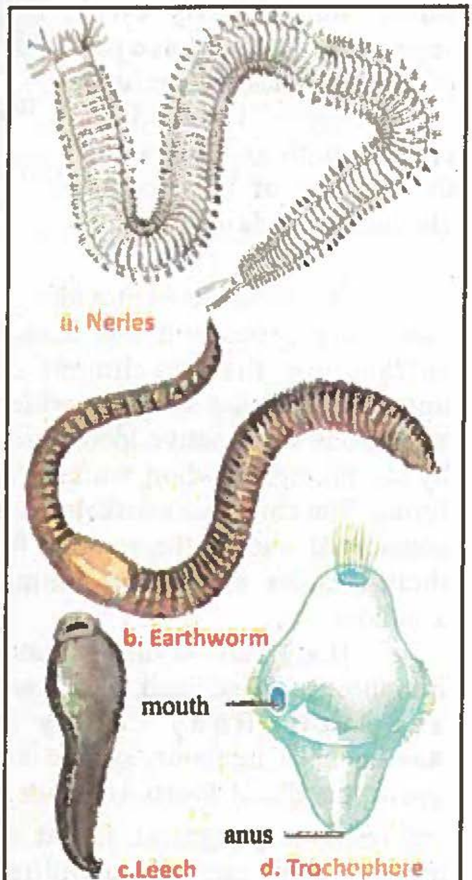


Fig: 9. 15 Annelida

(earthworm), *Hirudinaria medicinallis* (medicinal leech), Neries etc.

5. Phylum Arthropoda

The word arthropoda is derived from two Greek words; Arthoros means Jointed and Podos means limbs or legs hence, arthropoda includes all those animals having jointed appendages. This is the most successful group and the largest phylum of the animals.

Fig: 9.16 Nephridium

They are triploblastic and bilaterally symmetrical. The body is metamerically segmented. They have jointed limbs and generally every segment of the body has a pair of legs (also called limbs or appendages). The body is covered with an exoskeléton in the form of thick cuticle chemically made of **chitin**.

The exoskeleton provides not only protection but also a surface for the attachment of muscles with the help of which arthropods show active locomotion by swimming, crawling, walking or flying. The chitinous exoskeleton is considered one of the reasons for their success among the animal kingdom.

Body can be differentiated into three regions; head, thorax and abdomen. Body cavity is **haemocoel.** Circulatory system is of open type. Blood does not contain any respiratory pigment. Blood is called **haemolymph** because (it does not carry oxygen) it only carries food to different tissues of the body.

Science Technology and society

Processing of organic materials by earthworms into homogeneous and humus-like material is called vermicomposting. This material is a complex mixture of fecal matter of earthworms and microorganisms. In vermicomposting system, earthworms act as voracious feeder, modifying composition of organic waste, gradually reducing its organic carbon and C:N ratio and retains more nutrients (nitrogen, potassium, phosphorus, calcium).

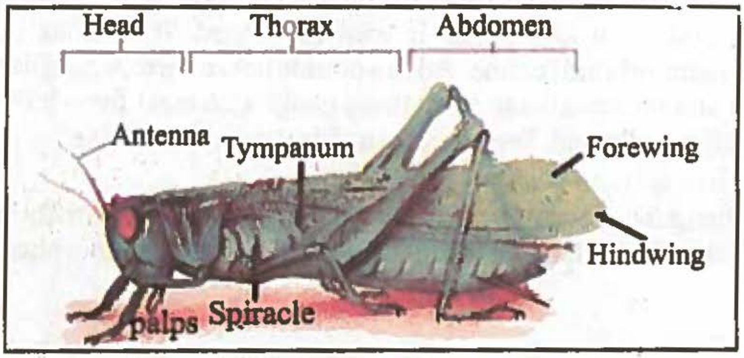


Fig: 9.17 Grass hopper showing morphological features

Respiration takes place in aquatic forms through gills and in terrestrial forms (especially insects) through **trachea.** Trachea are air tubes which divide repeatedly to form numerous fine branches distributed to all the tissues of the body. They communicate with exterior through openings on each side of the body known as **Spiracles.** Arachinids, a group of arthropods including scorpion, spider etc. respire through special structures, arranged side by side like books in a book shelf, hence called **book lungs.**

Excretion takes place either through **malpighian tubules** (as in insects) or green gland or coxal gland (as in crustacean). Fertilization is internal. Sexes are generally separate. Sexual dimorphism is generally present i.e. male and female can be differentiated from each other on the basis of their morphology. During development they exhibit either complete metamorphosis or incomplete metamorphosis. Some insects like honey bees, ants, termites etc. show social

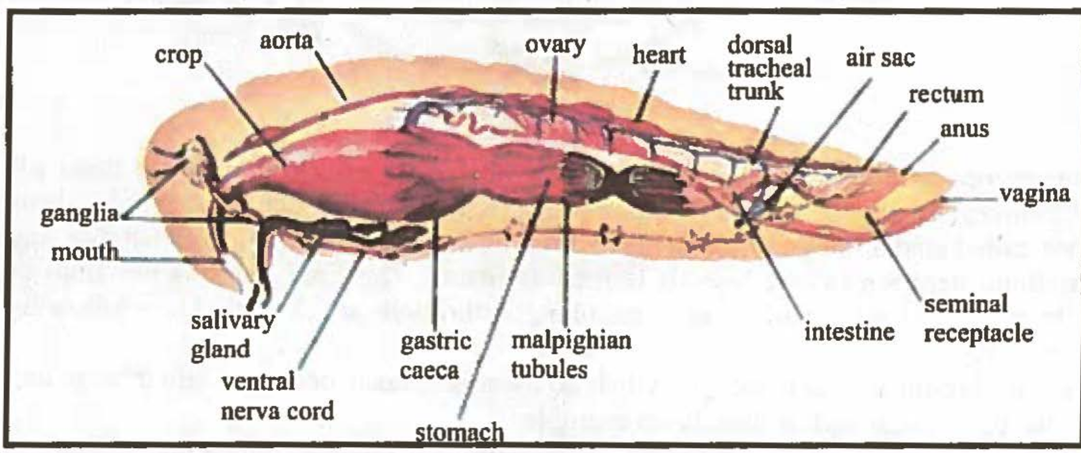


Fig: 9.18 Grass hopper showing anatomical features

behaviour. They live in colonies and divide their work among different groups.

Nervous system in arthropods is well developed. It consists of a pair of cerebral ganglia (simple brain) connected to a double nerve cord. A ganglion is present in each segment and nerves arising from these ganglia connect the whole body. The responses are well coordinated. Sensory organs are eyes and antennae.

a. Metamorphosis in Arthropodes

All the changes occurring from the fertilization of an egg to the formation of an adult are collectively called **metamorphosis.** During metamorphosis a larva

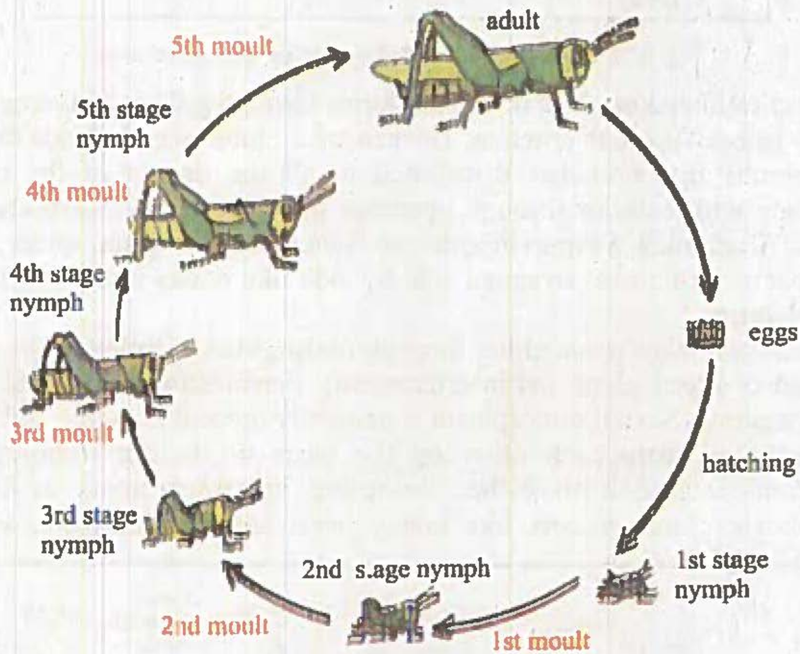


Fig: 9.19 Incomplete metamorphosis in Cockroach

undergoes a series of changes called **ecdysis** or **moulting** in which it casts off (removes) its skin many times to attain its maximum size. The stages between ecdysis are called stadia (singular stadium) and the form attained by an insect larva in any stadium between two ecdyses is termed as **instar**. The final instar is the adult or "Imago". On the basis of the metamorphosis arthropods are classified into following three groups.

a. Ametabola are the insects in which no metamorphosis occurs. Collembolan and other primitive wingless insects are example.

b. Hemimetabola are the insects in which incomplete metamorphosis takes place e.g. This type of meta morphosis is found in insects like Cockroaches, Wasps etc

c. Holometabola are those insects in which complete metamorphosis takes place.

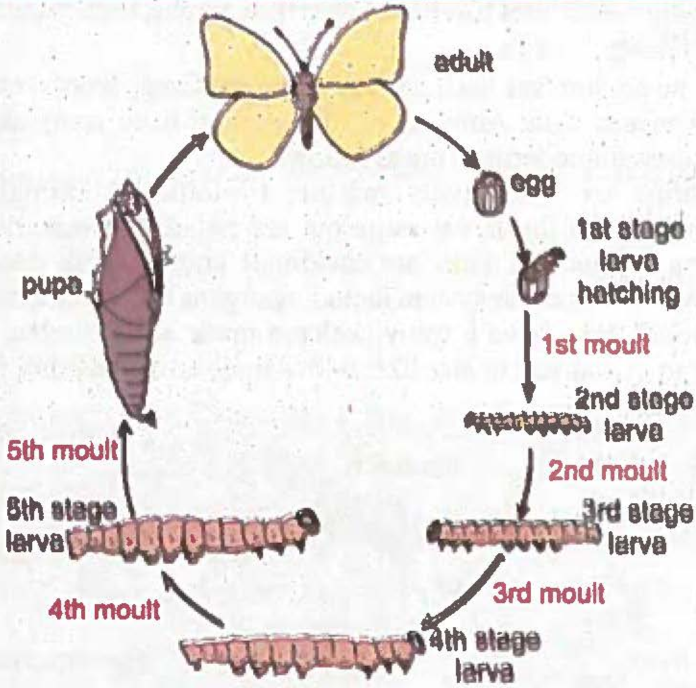


Fig: 9.20 Complete metamorphosis in butterfly

Science Technology and society

Apiculture is the scientific method of rearing honeybees. " It is the care and management of honey bees for the production of honey and the wax. In this method of apiculture, bees are bred commercially in apiaries, an area where a lot of beehives can be placed. Apiaries can be set up in areas where there are sufficient flowering plants. Sericulture, or silk farming, is the cultivation of silkworms to produce silk. Although there are several commercial species of silkworms, *Bombyx mori* (the caterpillar of the domestic silkmoth) is the most widely used and intensively studied silkworm.

Tidbit

Members of Onychophora, a group of arthropods, are believed to be separated from the main evolutionary line of the arthropods. They share characteristics with both annelids and arthropods, hence believed to be the most primitive arthropods and are considered a connecting link between Annelids and Arthropods. This class contains only about 70 species classified in 10 genera.

Most insects are holometabolites like flies, butterflies, moths, beetles etc.

6. Phylum Echinodermata

Name of the phylum has been derived from two Greek words; ekhinos means spine and derma means skin. Animals of this phylum have spiny skins. General characters of phylum echinodermata are as follows.

Echinoderms are exclusively marine, triploblastic animals. They are bilaterally symmetrical in the larval stage but are radially symmetrical as adults. Usually five arms are present. They are coelomate animals with distinct oral and aboral surfaces. A water vascular system including organs known as tube feet is found used for locomotion. They have a spiny skeleton made of calcareous plates. Body shape is rounded to cylindrical or star like, with simple arms radiating from a central body.

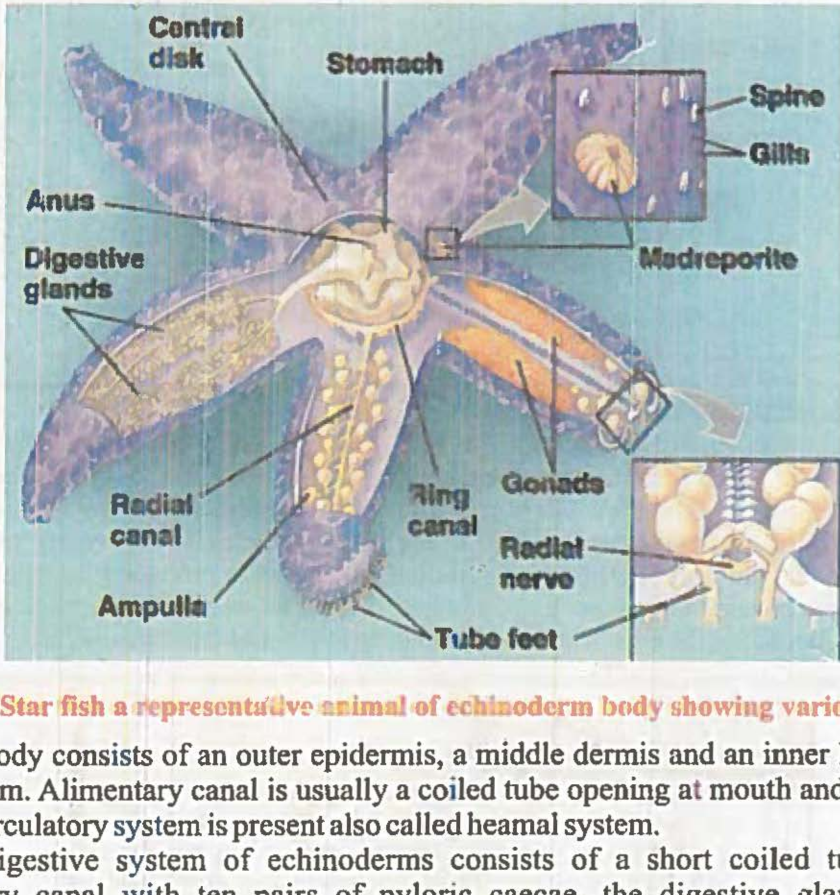


Fig: 9.21 Star fish a representative animal of echinoderm body showing various systems

Body consists of an outer epidermis, a middle dermis and an inner lining of peritoneum. Alimentary canal is usually a coiled tube opening at mouth and anus. A typical circulatory system is present also called heamal system.

Digestive system of echinoderms consists of a short coiled tube, the alimentary canal with ten pairs of pyloric caecae, the digestive glands. All echinoderms including starfish are carnivores. Food mainly consists of molluscs such as oysters, clams, mussels etc. Fish, crabs and other small animals are also taken as food. Tube feet help to capture prey.

Respiration occurs through a variety of structures e.g. papule in star fishes, peristomical gills in sea urchins, genital bursae in brittle star and cloacal respiratory tract in sea urchins. Tube feet also help in respiration. Nervous system is primitive consisting of network concentrated into the radial ganglia containing nerve chords. Sense organs are poorly developed.

Fig: 9.22 Bipinnaria larva

Sexes are usually separate with few exceptions. Reproduction is usually sexual but power of regeneration is well developed. Fertilization is external. Development is indeterminate including characteristic larvae called **bipinnaria larva** which undergo metamorphosis into the radially symmetrical adults.

Amoeboid cells known as amoebocytes roaming about in coelomic fluid absorb waste material and make their way out through the wall of rectal cecae. The amoebocytes are constantly produced in the body for this purpose.

Beside many nerve cells which lie among the epidermal cells, the radial nerve cord run along the ambulacral groove and unite with a nerve ring encircling the mouth.

The apical nervous system consists of a trunk in each arm which meets the other trunk at the centre of the disc. These trunks innervate the dorsal muscle of the arm. The tube feet are the principal sense organs. They receive nerve fiber from the radial nerve cord at the end of each radial canal, the radial nerve cord ends in a pigmented mass known as eye which is a light perceiving organ.

The star fish and other echinoderms have a remarkable power of regeneration. A single arm with part of central disc regenerates into a new animal.

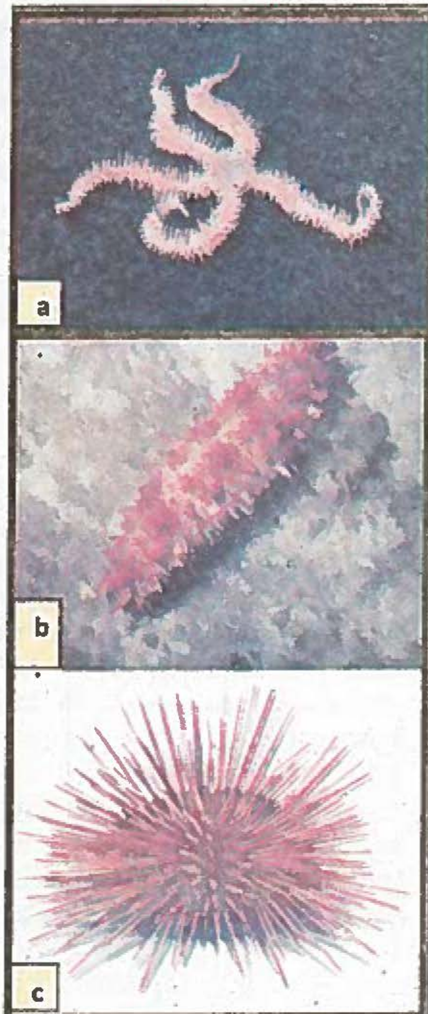


Fig: 9.23 Examples of Echinoderms
a. *Ophiothrix fragilis* (brittle star)
b. *Arbacia punctulata* (sea urchin)
c. *Thyone briareus* (sea cucumber

Echinoderms: Ancestry and Evolution

Echinoderms are very different from other phyla. Some of the differences are:

i) They have no parasitic member.
ii) They are all marine.
iii) They are unique in having bilateral

symmetry in larval stages but radial symmetry in adult stage which seems to be of secondary phyllogenetic origin.

Although they are very different from all invertebrate phyla, still they have a strong affinity to phylum chordate especially to subphylum Hemichordata. Ciliated larvae of certain Hemichordates (e.g. Tonaria larva of Balanoglossus) and bipinnaria larva of echinoderms are very much similar in shape and structure. Pattern of cleavage of fertilized egg, formation of mesoderm, anus, mouth and coelom in echinoderms and hemichordates is similar. Creatinine phosphate in the muscles of both echinoderms and chordates are similar which produce energy for muscular activity. On the basis of these similarities the echinoderms and chordates appear to be closely related and evolved from a common ancestor. For this reason these two groups are placed near each other. Examples of this phylum are *Asterias rubens* (star fish), *Opniothrix fragilis* (brittle star), *Arbacia punctulata* (sea urchin), *Thyone briareus* (sea cucumber) etc.

Tidbit

Brittle star is called brittle because it can break off its arm if it is injured. This "autotomy" allows the animal to leave its arm behind and escape from an enemy to save life. The broken arm regenerates rapidly into a new brittle star.

7. Phylum Hemichordata:

Hemichordates are worm like animals found in shallow ocean bottom. They are closely related to chordates but show many similarities with echinoderms. They are included in the group of animals called deuterostomes along with echinoderms and chordates. General characteristics of this phylum are as follows:

Body is soft and worm like and is divided into three regions, an anterior protosome, middle mesosome and posterior metasome or proboscis, collar and trunk. Every region is with a coelomic compartment. Body wall is made of unicellular epidermis with mucus secreting cells. Digestive tract is complete and consists of a long straight tube. Circulatory system is composed of a dorsal and ventral vessel. Gill slits are present behind the collar which performs the function of respiration. A single glomerulus connected to the blood vessel constitutes the excretory system of hemichordates. Brain occurs in the mesosome and the main nerve tracts are present in mid dorsal and mid ventral line. Notochord is absent. Cleavage is holoblastic and radial. **Tornaria larva** is formed during the life cycle which resembles bipinnaria larva of echinoderms. Many hemichordates make colonies. Examples are *Saccoglossus kowalevskii,* (Acron worm), *Balanoglossus sp.* etc.

8. Phylum Chordata

Name of the phylum has been derived from the word Notochord which is found in all the animals of this group (chord means thread or rope). Animals of this

phylum posses following three basic characters generally termed as **chordate** characters.

1. A dorsal stiff rod is found in all the chordates called as **notochord**. In lower chordates it is retained but in higher chordates (vertebrates) this rod is replaced by a vertebral column.
2. All chordates have a central, dorsal, hollow nervous system which lies above the notochord.
3. All chordates develop gill slits (sometimes called perforated pharynx) at least in the embryonic stage. In some chordates these are non functional and are afterwards closed while in others they are still functional as in fish and amphioxus.

Phylum chordata has been classified into two main divisions and three sub phyla

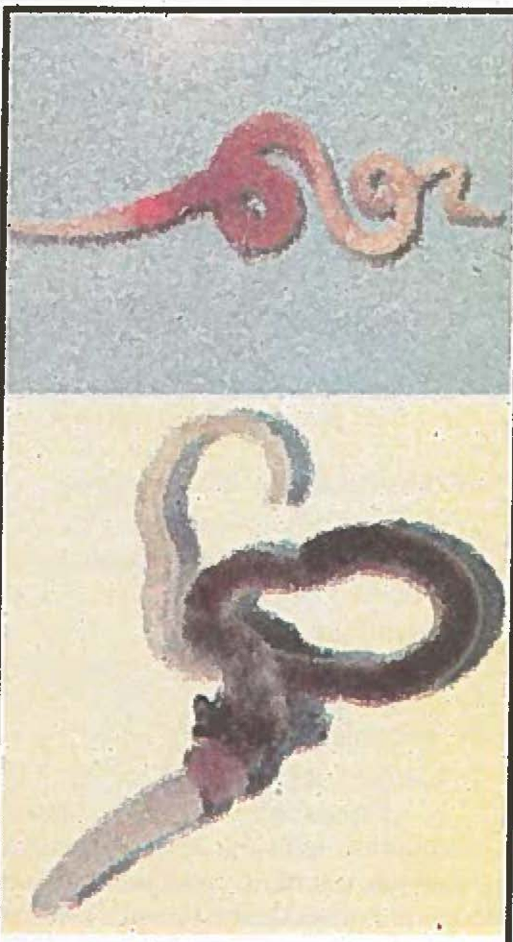


Fig:9.24 *Saccoglossus kowalevskii*

Division 1. Protochordata or Acrania

These chordates do not posses cranium (skull). They are also called as lower chordates. They are further divided into two sub phyla:

Sub phylum Urochordata:

Notochord is present only in free swimming larvae and is absent in adults. They are also called tunicate as their body is covered by a sheath called tunic which is chemically made of tunicin, a substance related to cellulose. Larvae are free swimming but adults are sessile. Examples are *Ciona intestinalis, Molgula* etc.

Sub phylum Cephalochordata:

Notochord is well developed in adults. Their body is in the form of a long, pointed rod, hence called as sea lancelet. They have a hollow nerve cord which runs through out the length of body. They are free living and swim about in water. They are filter feeders. Examples is *Branchiostoma* (amphioxus).

Division 2. Craniata

These chordates posses a cranium or skull in which brain is present. They are

Fig: 9.25 a. *Ciona intestinalis*, b. *Molgula*

included in sub phylum vertebrata.

9.5 Sub phylum Vertebrata

Vertebrates are divided in to following five groups or super classes:

1- Pisces or Fishes
2- Amphibia
3- Reptilia
4- Aves or Birds
5- Mammalia

Fig: 9.26 *Branchiostoma*

1. Class Pisces

Fishes are aquatic vertebrates which respire through gills and perform locomotion with the help of fins. Fishes are the largest group of vertebrates and constitute about 48 % of the total vertebrates. The number of living fish species is more than 29000. They are divided into three classes.

a. Class Cyclostomata or Agnatha

These are the most primitive jawless fishes having circular mouth. These fishes have a long, eel like body. Skin is naked i.e. without scales. They lack paired fins (appendages). Seven pairs of gills are found which open separately to the outside and are not covered with operculum.

Their skeleton is of lower grade, fibrous cartilage. They do not posses a stomach because of their parasitic way of life. Mouth is adapted for sucking. Sexes are separate. Examples are *Petromyzon marinus* (lamprey) and *Maxine glutinosa* (hag fish).

b. Class Chondrichthyes: (cartilaginous fishes)

Their skeleton is made of cartilage. They have streamlined bodies. All the chondrichthyes live in marine environment. Their mouth is ventral. Their body is

covered with **placoid scales** which are very small and numerous and give the skin a touch of sand paper.

Circulatory system is with many pairs of aortic arches. They have heterocercal tails in which dorsal lobe is longer than ventral lobe. Respiration takes place through 5- 7 pairs of gills. Gills are not covered with operculum and open separately. Most of them are carnivorous and sharks are very active hunters.

Swim bladder is absent.

Sexes are separate and many of them are viviparous. Examples are sharks, rays, skates and chimaeras.

c. Class Osteichthyes: (bony fishes)

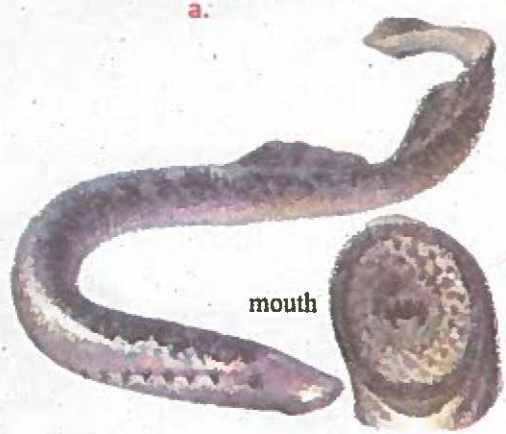
These fishes have a skeleton made of bone hence called bony fishes. They are the most successful group of fishes and inhabit all types of aquatic habitats. Their body is covered with scales of different types; Median fins i.e. dorsal fin, anal fin, caudal fin and paired fins i.e. pectoral and pelvic fins are present in bony fishes.

A specific organ swim bladder is found which is hydrostatic in function and provides buoyancy to the fish in water. They respire through well developed gills which are covered with a bony cover called **operculum.**

Jaws may be with or without teeth. Brain is developed with 10 pairs of cranial nerves. Heart consists of an auricle and a ventricle. Blood contains haemoglobin as respiratory pigment and its colour is red.

Sexes are separate and except few species the fertilization is external. Majority of bony fishes are oviparous but some are ovo-viviparous and viviparous.

a.



b.

Fig:9.27 a. Hag fish
b. Lamprey (See the circular mouth)

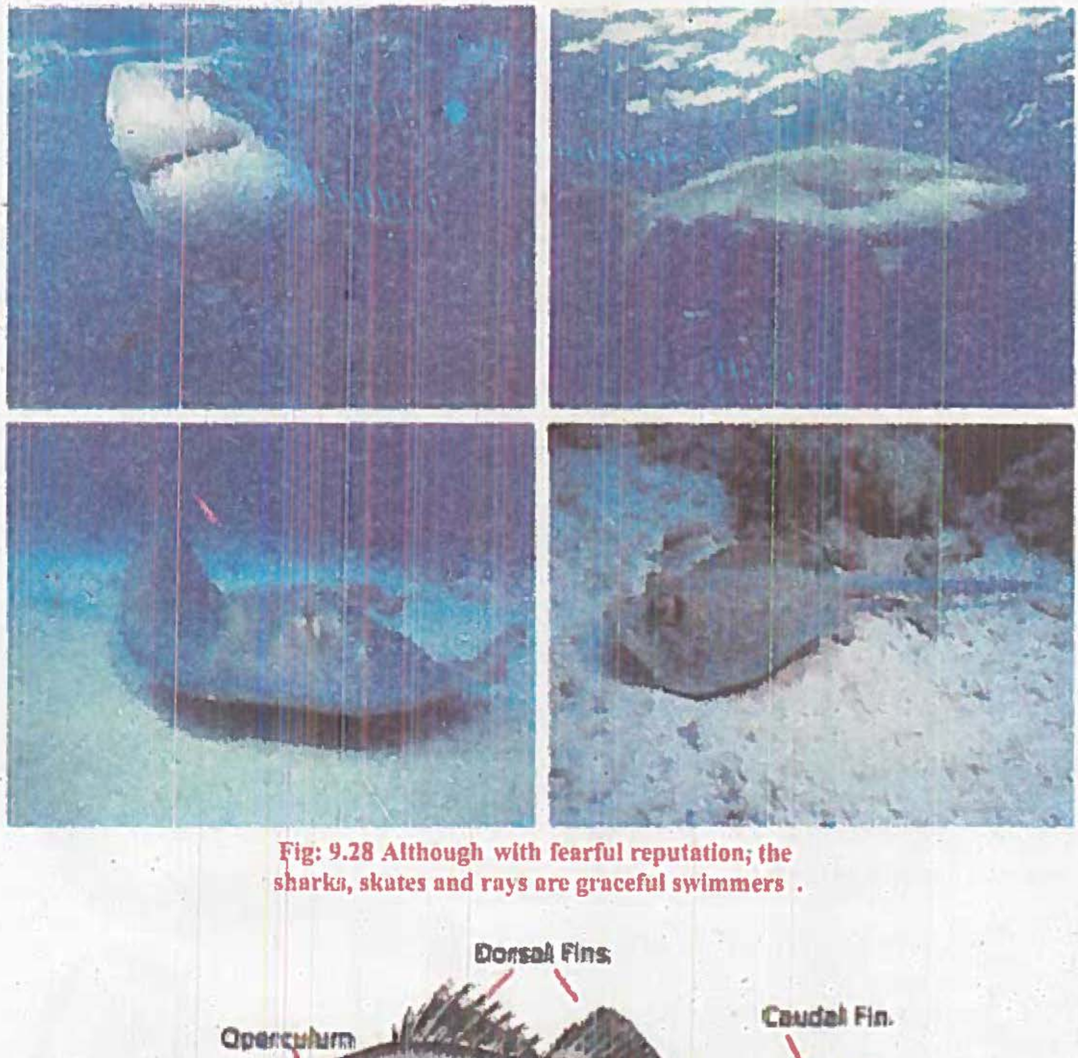


Fig: 9.28 Although with fearful reputation; the sharks, skates and rays are graceful swimmers .

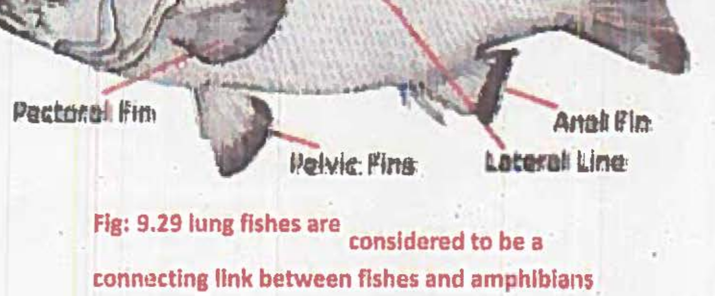


Fig: 9.29 lung fishes are considered to be a connecting link between fishes and amphibians

For your information

Fishes of sub class **Dipnoi** are called lung fishes. There are only three species left in the world. These fishes aestivate in the holes dug in the mud for few dry months and during this period respire through the extremely vascularized swim bladder which acts as a lung. When the rainy season comes again they come out and start their normal life in which they respire through gills like all other bony fishes.

Tidbit

A very prominent feature of the some fishes is their migration to reach their feeding or breeding grounds. They travel thousands of kilometers in this process. For example, salmon fish.

2. Class Amphibia

Name of the class has been derived from a Latin word Amphi which means both. The animals of this class have characters of both aquatic and terrestrial animals. Amphibia are considered on the border line of these two groups. Transition from aquatic life to terrestrial life is clearly indicated in amphibia. It is believed that certain lobe fin fishes of the group **dipnoi** came to live in shallow water. They started crawling from one pool to another in search of food and to avoid overcrowding and competition. In this way they used to spend some time on land. These fishes are believed to give rise to amphibians.

Amphibia are poikilothermic (cold blooded) vertebrates. Sexes are separate and fertilization is external. They breed in water and their larva called **tadpole larva** lives in water and respires through gills and swim with the help of their laterally flattened tail. After developing gills during metamorphosis, they come out of water and start a terrestrial life. In some amphibia like Necturus the gills are retained throughout life. They are tetrapods having two

Fig: 9.30 a. salamander, b.newt, c. necturus (tailed)

pectoral and two pelvic limbs. Some forms are **legless** e.g. caecilians. They have **webbed feet** but fingers are without claws. Their skin is pigmented, smooth and glandular which is always kept moist and help in respiration. Heart in amphibia is three chambered; two auricles and a single ventricle. Two additional tubes (sometimes considered chambers) truncus arteriosus and sinus venosus are also present. Their circulatory system is not very perfect as mixing of oxygenated and deoxygenated blood takes place in the ventricle. Most amphibians **hibernate** during winter. In this process they dig deep in the mud and survive by getting energy from the fat bodies deposited around their kidneys. Examples are frog, toad (tailless) and salamander, newt, necturus (tailed)

3. Class Reptilia

Reptiles are true land vertebrates. Their bodies are bilaterally symmetrical and can be divided in to four regions; head, neck, trunk and tail. They are poikilothermic, **pentadactyle** (having five fingers) tetrapods. They are terrestrial but some species secondarily has adopted aquatic life like aquatic snakes and turtles. They are lowest amniotes i.e. their embryos are surrounded by a proteotive covering amnion. Other protective membranes called **extra embryonic membranes** i.e. yolk sac, chorion, and allontoise are also found.

Fig: 9.31 Lizards, snakes, tortoises, turtles and Tuatara

Sexes are separate and fertilization is internal. They are **oviparous** and lay **shelled eggs** with considerable amount of yolk which provide all the nutritional required by the developing embryo within the egg, hence there is no larval stage and the young ones hatch out fully formed from the egg. Their skin is thick, scaly and devoid of glands. This is why skin is very dry and impervious to water.

Exoskeleton is present in the form of nails and epidermal scales and digits are with claws. Teeth are present on the jaws except in turtle and tortoise. All reptiles are carnivorous. Heart is four chambered with two auricles, a completely or partially divided ventricle and a pair of systemic arches. Colour of the blood is red due to the presence of haemoglobin as respiratory pigment. Respiration takes place through lungs which have spongy texture. Gill slits appear during embryonic stages but gills never

> **Tidbit**
>
> Most of the Lizards never take water in their life. They survive with conserving the water present in their food.

develop in reptiles. Excretory organs are metanephric kidneys. Being adapted to live on land they are **uricotelic** i.e. excrete uric acid crystals to conserve water. Most of the modern
reptiles live in temperate and tropical areas of the world.

It is believed that those amphibia which had totally departed from their aquatic environment were the ancestors of the reptiles. Reptiles were once the most dominant group on the land and that time in geological history is termed as **age of reptiles.**

Reptiles flourished in **Mesozoic** era (225- 65 million years back). Modern reptiles are the descendents of the Dinosaurs of **Jurassic** era (195- 136 million years back and **Cretaceous** era (136- 65 million years back). At the end of Mesozoic era change in climatic conditions and environmental hazards caused the reptiles to become extinct. Those who could survive and are found today include lizards, snakes, tortoises, turtles and the Tuatara (*Sphenodon punctatum*) of New Zealand, a species also called living fossil.

4. Class Aves

All the birds are included in this class. Birds are unique among vertebrates in having feathers on their bodies. Both birds and mammals are considered to be evolved from reptilian ancestors. Scales on the legs and claws are the reptilian characters which are still very prominent in birds. Evolutionary history of birds is very interesting. In 1861 from the rocks of Jurassic period, fossil of a bird was found which was given the name of Archaeopteryx, the lizard tailed bird. It is of the size of a crow. Interesting about it is that it has characters of both reptiles and birds so can be considered a transition species between the two groups.

Some of the birds like characters of archaeopteryx are:

i- Well developed contour and flight feathers covering the body.

ii- Forelimbs modified in to flying wings.

iii- Tail with two rows of feathers.

iv- Skull large with a single occipital condyle.

v- Jaws elongated to form a beak.

Reptilian characters of archaeopteryx

i- Presence of scales on the legs.

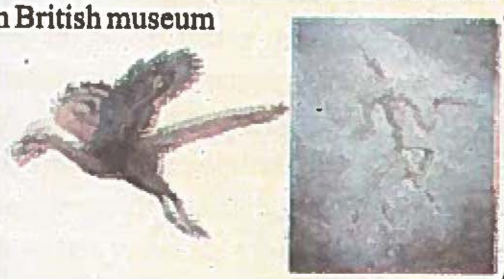
ii- Bones solid and heavy without air spaces.

iii- Jaws with teeth present in sockets.

iv- A long, tapering lizard like tail consists of 20 caudal vertebrae.

Tidbit

One specimen of archaeopteryx is present in Berlin museum and the other in British museum



v- Nine to ten cervical vertebrae.

vi- No fusion of trunk and sacral vertebrae.

vii- Sternum not keeled. Free cervical and abdominal ribs are also present.

viii-Simple brain with cylindrical cerebral hemisphere and unexpanded cerebellum.

ix- Fore limbs with three clawed fingers.

The above evidences prove that archaeopteryx was a **connecting link** between reptiles and birds. Birds gradually evolved and became one of the most successful group of vertebrates

a. Distinguishing Characteristics of Birds

They are **homoiothermic** i.e. warm blooded animals because they can maintain their body temperature. The body is covered by different coloured feathers which are epidermal exoskeleton. Body is fusiform (streamlined) to allow better movement in air with less resistance. Fore limbs are modified into wings for flight. They have adapted a bipedal life and hind limbs are used for walking on land. The aquatic birds posses webbed feet. Skin is without epidermal glands except for uropygial gland present at the base of tail.

Bones of the birds are hollow having air spaces which make them light in weight. Sternum is well developed in to a **keel** which not only helps in cutting the air during flight but also provide additional area for the attachment of muscles. Jaws are without teeth and are modified in the form of a beak. Digestive system has a crop to store the food and a gizzard to grind it.

Heart is four chambered with two auricles and two ventricles. A single aortic arch is present which curves to the right side. Blood is red due to haemoglobin contained in oval, nucleated RBCs.

Vocal cords are not present in larynx but a special sound box syrinx is present at the junction of trachea and bronchi. Lungs are provided with extra **air sacs**. These air sacs are extended in to viscera.

Eyes are provided with a third eyelid, the **nictitating membrane** which can be drawn across the eye. A rudimentary pinna is present outside the external auditory opening.

Excretory organs are metanephric kidneys. Ureters open in common cloaca and nitrogenous wastes are excreted in the form of semi solid urates.

Sexes are separate and sexual dimorphism is found in many birds. Fertilization is internal. Female has only left ovary and oviduct is well developed. Females have shell

secreting glands. Birds are oviparous and have eggs with considerable amount of yolk covered with a hard calcareous shell. Birds are amniotes and have all the four **extra embryonic membranes** i.e. amnion, chorion, yolk sac and allontoise. In many birds parental care is very developed.

6. Types of Birds

Birds are of two types:

i. Flightless Birds

ii. Flying Birds

i. Flightless Birds are those which do not fly in the air. They are called running birds as instead of flying they secondarily has adapted a running mode of life. Their bones are not hollow and sternum is not keeled. Tail feathers are irregularly arranged e.g. ostrich, emu, kiwi, cassowary, penguin etc.

a. ostrich b. emu c. cassowary

Fig: 9.32 Flightless Birds

ii. Flying Birds are the birds with strong wings for flight and keeled sternum. Their bones are hollow. Tail feathers are well developed and are used for steering the bird in air during flight. e.g. pigeon, sparrow, parrot, eagle, owl etc.

5. Class Mammalia

Mammals are the animals in which females nourish their babies with milk produced by mammary glands.. The development of brain and nervous system in mammals is the most remarkable character which has placed them at the top of the evolutionary tree.

Because of possessing solid and hard bones and being the most recently evolved forms, the fossil record of mammals is more continuous and complete. Mammals are believed to be evolved from reptiles. Ancestors of mammals lived simultaneously with reptiles in Jurassic period and are called mammal like reptiles. A

fossils animal (named varanope) has been recovered from Texas which has 50% mammalian characters. The ancestors of mammals were of the size of mice and lived on trees. Mammals became dominant in **Cenozoic era.** Today we are living in the **age of mammals.**

Following are general characteristics f mammals:

Mammals are warm blooded, air breathing, tetrapods which are mostly terrestrial. Their body is covered with hairs which insulate the body and help in maintaining temperature. Mammals have two pairs of pentadactyle limbs which are adapted for walking, running, climbing, burrowing, swimming, gliding. In aquatic orders hind limbs are absent. Skin is glandular with sweat glands and sebaceous glands and mammary glands in females for secreting milk. Brain is well developed with two large cerebral hemispheres and 12 pairs of cranial nerves. Sense organs are well developed. Eyes are protected by movable eyelids. Ears have an external **pinna** for collection of sound waves. Internal ear contains a set of three bones viz. **incus, malleus** and **stapes** which are the smallest bones of the body. Sense of smell, taste and touch are also well developed.

Respiration takes place through lungs which are spongy in texture due to the presence of air sacs. Larynx is well developed with vocal cords. Heart is four chambered and a complete separation of oxygenated and deoxygenated blood is maintained. Only left aortic arch is present. Colour of the blood is red due to the presence of haemoglobin in biconcave, non nucleated RBCs. Nitrogenous wastes are filtered by highly glomerular kidneys and are excreted in the form of urine. Teeth are present in jaws which have their roots in the jaws. Canine, incisors, premolar and molar type teeth are found in varying numbers in mammals.

Sexes are separate and sexual dimorphism is prominent in most mammals. Testes of male mammals lie in scrotal sac outside the body. Fertilization is internal and they are viviparous. Embryo is kept inside the body of the female for development, the process is called gestation. To absorb nutrition from the body of mother a glandular tissue develops between foetus and uterine wall of the mother called **Placenta.** Mammals are also **amniotes.** The extra embryonic membranes help in the formation of placenta. Parental care is highly developed in mammals.

Mammals are divided into three sub classes.

a. Subclass Prototheria or monotremata
b. Subclass Metatheria or marsupials
a. Subclass Eutheria or placentalia

a. Subclass Prototheria or Monotremata

These are the most primitive mammals and are also called as egg laying mammals. They have certain characters of reptiles like they lay eggs but these eggs are kept in long oviduct where they are fertilized and later on development takes place. In these mammals there is no connection between the body of mother and foetus for

transfer of nutrients.

These animals are more rightly be called as ovo- viviparous. The youngs are given birth in an immature form and are nourished by the teats present on the ventral side of the body in females until they grow enough to survive and start taking their own food.

Fig: 9.33 Platypus and spiny ant eater

Prototheria are restricted to Australian region and are found in Australia, Tasmania, New Guinea and their neighbouring islands. They are insectivorous, borrowing, nocturnal animal. In adults teeth are absent and a horny beak is found. Their body temperature varies between 25- 28 °C. Example of these mammals are duck billed platypus (*Ornithorhynchus*) and spiny ant eater (*Tachyglossus*).

b. Subclass Metatheria or Marsupials

These mammals are also called pouched mammals. Females of these animals bear a pouch or **marsupium** on the ventral side of the belly in which young ones are kept as they are born in a very under developed and immature stage. Teats of the mammary glands are present in the pouch from which the babies suckle milk. In these animals placenta is poorly developed and babies come out of the body earlier in immature form.

Fig: 9.34 Marsupials

Marsupials are also confined to Australian region with the exception of only one species, American opossum. Their body is covered with hairs. They are terrestrial, burrowing or arboreal (living in trees) in habit. Examples are Kangaroo, Opossum, Koala etc.

c. Subclass Eutheria or Placentalia

These animals are the true mammals having the highest degree of evolution of brain and body structures. They are also called placental mammals as placenta of different types is formed in these mammals with the help of which the developing embryo gets nourishment and oxygen from the body of mother and removes its metabolic wastes. Young ones develop inside the uterus to a relatively mature stage. After birth mother feeds them on her milk produced in the mammary glands with well developed teats. Teeth are present in jaws. Cloaca is absent and urino-genital duct opens independently of rectum. Testes are in scrotum hanging outside the body either throughout life or at least descend to scrotum during breeding season.

Eutheria are divided into sixteen orders. Some important orders with examples are mentioned below:

Insectivora: Feed on insects, includes moles and shrews.

Chiroptera: Flying mammals like bats, flying squirrels.

Cetacea: Aquatic mammals e.g. whale, dolphin. porpoises, sea lion etc.

Carnivora: Flesh eating like dog, cat, lion. Wolves

Rodentia: Cutting habit like rats, mice, squirrel, beavers etc.

Edentata: Adults with no or poorly developed molar teeth like South American anteater, sloths.

Pholidota: Body covered with large, overlapping, horney scales e.g. Pengulin

Proboscidea: Have a long trunk like elephant.

Perissodactyla: Odd- toed hoofed mammals like, horse, zebra etc.

Artiodactyla: Even- toed hoofed mammals like cow, goat, deer etc.

Primates: Mammals withy highest brain development like lemur, monkeys, apes, tarsiers, human beings etc.

Do You know?

Markhor is the national animal of Pakistan.

KEY POINTS

- Animals have been evolved from the single celled organisms included in kingdom Protoctista, but it has yet to be decided that from which group of protoctists, they have evolved.
- System of naming of animals is called **binomial nomenclature.**
- According to modern classification simplest animals which don not have tissues organized into organs belong to subkingdom **Parazoa.** Animals of all other phyla are included in subkingdom **Eumetazoa.**
- In diploblastic animals the body is composed of two layers of cells.
- In triploblastic animals the body is composed of three layers of cells.
- Triploblastic animals may be classified into acoelomates, pseudoceolomates and coelomates.
- Porifera possess skeleton in the form of spicules.
- Coelenterates possess a body cavity or ceolenteron or enteron.
- Flat worms (platyhelmenthes) are bilaterally symmetrical triploblastic, unsegmented and hermaphrodite. Organs of excretion in flat worms are flame cells.
- Round worms and thread worms (nematodes) are bilaterally symmetrical, triploblastic, unsegmented animals in which the sexes are separate.
- Annelids have bilaterally symmetrical bodies.
- Arthropods posses paired jointed appendages.
- Organs of respiration in arthropods are the trachea, gills or book lungs.
- Insects belong to class insecta (phylum Arthropods). Their bodies are divided in to a head, thorax and abdomen. The thorax bears two pairs of wings and three pairs of legs.
- Organs of excretions in insects are malpighian tubules.
- Molluscs are fundamentally bilaterally symmetrical generally provided with shells of various types.
- Echinoderms are radially symmetrical with calcareous skeleton.Organs of locomotion are the tube feet which are connected with water vascular system.
- Phylum chordata characteristics are presence of notochord at least in the embryonic condition, presence of gills slits at least in the embryonic condition and presence of dorsal hollow central nervous system.

EXERCISE

A. Select the correct answers in the following questions.

1 Animals are believed to be evolved from:

a. Non living matter b. Higher plants
c. Water Plants d. Prokaryotes

2. The most important and basic category of taxonomy is:

a. Phylum b. Class
c. Family d. Species

3. An animal found from ocean was observed to have no tissue organization is most likely to be the member of phylum.

a. Porifera b. Coelentrata
c. Echinodermata d. Hemichordata

4. Cells of the inner lining of the endoderm in diploblastic animals are called

a. Cnidoblast b. Choanocytes
c. Pinnacocytes d. Amoebocytes

5. Animals found in more than one morphological form are said to exhibit:

a. multigenecity b. polymorphism
c. pseudomorphism d. isolation

6. A flat worm was divided into three pieces during an experiment and was kept in the nutrient medium. All parts grow into new worm. The animals may be:

a. liver fluke b. tape worm
c. planaria d. hydra

7. Group of vertebrates in which placenta is formed

a. Fishes b. Amphibia
c. Aves d. Mammalia

8. Organs of excretion in annelids are

a. Flame cells b. Nephridia
c. Malpighian tubules d. Kidneys

EXERCISE

9. Members of the order 'perissodactyle' are also named as:
   a. ungulates b. hoofed mammals
   c. eutheria d. All of the above

10. Acoelomates are characterized by:
    a. the absence of brain.
    b. the absence of mesoderm
    c. a solid body without a cävity surrounding internal organs.
    d. a coelom that is not completely lined with mesoderm.

11. Which of the following characteristic is probably most responsible for the great diversification of insects on land?
    a. Segmentation b. Antenna
    c. Bilateral symmetry d. Exoskeleton

12. Mammals and living birds share all of the following characteristics EXCEPT:
    a. endothermy.
    b. descent from common amniotic ancestor.
    c. a dorsal, hoallow nerve cord.
    d. an archosaur common ancestor.

13. Archaeopteryx shows features of:
    a. reptiles and mammals. b. reptiles and amphibians.
    c. reptiles and aves. d. aves and mammals.

B. Write short answers to the following questions.

1. Why certain animals are called living fossils?
2. What is the reason for the formation of larva during the life cycle of many animals?
3. What is the importance of polymorphism?
4. Cuttle fish, jelly fish, star fish are invertebrates and are not fishes. Why many invertebrates are called fish?
5. Why the reptiles excrete nitrogenous wastes in the form of uric acid crystals?
6. In what heamolymph is different from blood?

EXERCISE

7. Differentiate between Proterostomes and Deuterostomes.
8. Why alternation of generation is required .
9. What is the difference between haemocoel and coelom?
10. List down three organisms, each representing radial symmetry and bilateral symmetry?
11. Differentiate between prototheria and metatheria.

D. Write down the detailed answers of these question.

1. Describe the importance of classification in animal kingdom. What are different categories used for classification?
2. What are the salient features of phylum Annelida? Describe their economic importance as well.
3. Describe the parasitic adaptations in phylum platyhelminths.
4. Compare the structure of heart in different phyla of animal kingdom and especially in different classes of vertebrates.
5. Discuss the distinguishing characters of phylum arthropoda. How will you evaluate the economic importance of class insecta?
6. What adaptations are found in birds for aerial life? Describe evolutionary history of birds with special reference to the fossil birds.
7. Write short notes on the following.
   a. Binomial nomenclature
   b. Parazoa
   c. Poikilothemic animals

Projects

- Make a collection of insects present in your locality. Identify their scientific names. An exhibition of this collection may be arranged under the guidance of teacher.
- Working in group of four, prepare a presentation discussing the main causes/events of extinction of major animal species. Collect information from reference books and internet. Share your findings in the classroom.

Chapter

10

Form and Functions in Plants

At the end of this chapter students will be able to:

- List the macro and micronutrients of plants highlighting the role of each nutrient.
- State the examples of carnivorous plant.
- Explain the role of stomata and palisade tissue in the exchange of gases in plants.
- Relate transpiration with gas exchange in plants.
- Describe the structure of xylem vessel elements, sieve tube elements, companion cells, trachieds and relate their structures with functions.
- Explain the movement of water between plant cells, and between the cells and their environment in terms of water potential.
- Explain the movement of water through roots in terms of symplast, apoplast and vacuolar pathways.
- Explain the movement of water in xylem through TACT mechanism.
- Describe the mechanisms involved in the opening and closing of stomata.
- Explain the movement of sugars within plants.
- Define osmotic adjustment.
- Explain movement of water into or out of cell in isotonic, hypotonic, and hypertonic conditions.
- Describe osmotic adjustments in hydrophytic (marine and freshwater), xerophytic and mesophytic plants.
- Explain the osmotic adjustments of plants in saline soils.
- List the adaptations in plants to cope with low and high temperatures.
- Explain the turgor pressure and explain its significance in providing support to herbaceous plants.
- Describe the structure of supporting tissues in plants.
- Define growth and explain primary and secondary growth in plants.
- Describe the role of apical meristem and lateral meristem in primary and secondary growth.
- Explain how annual rings are formed.
- Explain influence of apical meristem on the growth of lateral shoots.
- Explain the role of important plant growth regulators.
- Explain the types of movement in plants in response to light, force of gravity, touch and chemicals.
- Define photoperiodism.
- Classify plants on the basis of photoperiodism and give examples.
- Describe the mechanism of photoperiodism with reference to the mode of action of phytochrome.
- Explain the role of low temperature treatment on flower production especially to biennials and perennials.

Introduction

The plants upon which we depend for the food we eat, and for the oxygen we breathe, depend in turn upon the soil. A good soil supplies the plants with the mineral elements they use. Mineral nutrition thus comprises the study of how plants obtain mineral elements (either through water, air or soil) and utilize them for their growth and development. Like any other living organisms, plants lead a versatile life. They have a system for proper gaseous exchange, transport of materials, and an ability to adjust to the changes taking place in the environment. Plants are constantly undergoing the process of growth and development which is regulated by specialized tissue and hormones. In this chapter all these different aspects will be discussed.

10.1 Plant Nutrition

Plants need a variety of nutrients in order to sustain their daily life processes. Depending upon the amount of each nutrient required the mineral nutrients are divided into two groups: macronutrients and micronutrients

a. Macronutrients

Macronutrients can be divided into two more groups: primary and secondary nutrients. The primary nutrients are nitrogen (N), phosphorus (P), and potassium (K). These major nutrients are usually less in soil because plants use these in large amounts for their growth and survival. The secondary nutrients are calcium (Ca), magnesium (Mg) and sulfur (S). These are usually present in reasonable amounts. Large amounts of Calcium and Magnesium are added when lime is applied to acidic soils. Sulfur is usually found in sufficient amounts from the slow decomposition of soil organic matter.

b. Micronutrients

Micronutrients are those elements essential for plant growth which are needed in only very small quantities. These elements are sometimes called minor elements or trace elements. The micronutrients includes boron (B), copper (Cu), iron (Fe), chlorine (Cl) etc. Recycling organic matter such as grass clippings and tree leaves is an excellent way of providing micronutrients to growing plants.

For Your Information

Soil pH is one of the most important soil properties that affects the availability of nutrients. Macronutrients tend to be less available in soils with low pH and micronutrients tend to be less available in soils with high pH. **Lime** can be added to the soil to make it less sour (acid) and also supplies calcium and magnesium for plants to use. Lime also raises the pH to the desired range of 6.0 to 6.5.

Table: 10.1 A Summary of Mineral Nutrition in Plants

Macronutrients	Used in the form of	Functions
Carbon	CO_2	Component of organic compounds
Oxygen	H_2O or O_2	Component of organic compounds
Hydrogen	H_2O	Component of organic compounds
Nitrogen	NO_3- or NH_4-	Amino acids, proteins, nucleotides, nucleic acids, chlorophyll, and coenzymes
Potassium	K-	Enzymes, amino acids, and protein synthesis. Activator of many enzymes. Opening and closing of stomata.
Calcium	Ca^{+2}	Calcium of cell walls. Enzyme cofactor. Cell permeability.
Phosphorus	$H_2PO_4^-$ or H_3PO_4	Formation of "high energy" phosphate compounds (ATP and ADP). Nucleic acids. Phosphorylation of sugars. Several essential enzymes. Phospholipids.
Magnesium	Mg^{2+}	Part of the chlorophyll molecule. Coenzyme A.
Sulfur	SO_4^{+2}	Some amino acids and proteins. Coenzyme A.
Micronutrients		
Iron	Fe^{2+} or Fe^{3+}	Chlorophyll synthesis, cytochromes, and nitrogenase.
Chlorine	Cl^-	Osmosis and ionic balance; probably essential in photosynthetic reactions that produce oxygen
Copper	Cu^2	Activator of certain enzymes.
Manganese	Mn^2	Activator of certain enzymes.
Zinc	Zn^{2+}	Activator of certain enzymes
Molybdenum	MoO	Nitrogen fixation. Nitrate reduction.
Cobalt	Co^{2+}	Required by nitrogen-fixing organisms.
Sodium	Na^+	Osmotic and ionic balance, probably not essential for many plants. Required by some desert and salt marsh species. May be required by all plants that utilize C-4 photosynthesis

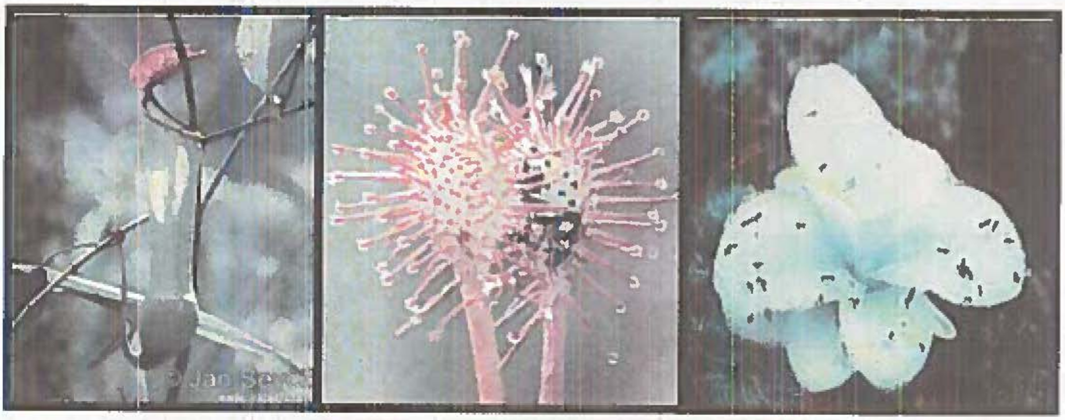
10.1.1 Special Mode of Nutrition in Plants

Plants are basically autotrophs because they are capable of manufacturing their own food. However, there are certain plants which have adopted certain heterotrophic mode of nutrition for their survival.

For Your Information

Deficiencies of the nutrients like nitrogen, phosphorus, potassium, and magnesium result in chlorosis (yellowing) and eventual necrosis (death) of older mature leaves. These nutrients are mobile elements that can be translocated from older to new leaves if their supply from the soil becomes limited and the young leaves become deficient in them. This translocation depletes the older leaves of these essential nutrients, leading to chlorosis and necrosis.

Depending upon the source of food such plants may carry out Parastic nutrition in which parasitic plants wholly depend upon other plant or in some cases plants may be involved in saprophytic nutrition in which saprophytic plants extracts nutrition form dead organic matter. However, the most interesting example of heterotrophic nutrition is the carnivorous plants which feeds on insects.



a. Pitcher Plant b. Sundew c Butterworts

Fig: 10.1 Carnivorous plants.

Carnivorous plants may be subdivided into 2 major groups; those with passive traps and those with active traps. For some of these traps the actual method of insect decomposition involves digestive enzymes produced by the plant and bacterial decay within the trap.

A classic passive trap is the "pitfall trap" of pitcher plants, including *Darlingtonia* and *Sarracenia* of the Sarraceniaceae, and *Nepenthes* of the Nepenthaceae, where an insect falls into a vase-like modified leaf. Downward-pointing hairs on the slippery walls prevent the insect from crawling out, and the helpless victim ultimately drowns in a pool of digestive enzymes at the bottom.

Examples of active traps are the "flypaper" or adhesive traps of sundews (*Drosera*, Droseraceae) and butterworts (*Pinguicula*, Lentibulariaceae). In both of these unrelated genera, the leaves are covered with sticky, gland-tipped hairs (*Drosera*) or a sticky layer of mucilage (*Pinguicula*) which entangle the hopeless, struggling victim.

10.2 Role of Stomata in Gaseous Exchange and Transpiration

The small pores on the epidermis of leaves are called stomata. Each stoma or stomatal pore is surrounded by two guard cells. In dicot plants guard cells are kidney shaped or bean shaped. In monocot stomata, guard cells are dumb bell shaped .

The inner wall of guard cells are thick and non-elastic. The outer wall is thin and elastic. The adjoining cell walls of two guard cells around the pore are free and not attached with each other and this help them to stretch laterally during stomatal opening.

The epidermal cells surrounding the guard cells are called subsidiary cells. The stomatal pore, guard cells and the subsidiary cells are together called stomatal apparatus. Each guard cell contains a single nucleus and numerous chloroplasts. Starch is synthesized in guard cell by chloroplast and sugars transported to adjacent mesophyll cells and they are characterized by accumulation of starch during night (in dark) and their degradation during the day (in light).

Mesophyll cells accumulate starch during the day and decrease during the night. This property helps in the opening and closing of stomata.

Transpiration is loss of water through the aerial parts of the plant into the atmosphere by evaporation. Over 90% of the total transpirational water loss from the plant takes place through stomata.

Stomata are structures found within the leaf blade and are responsible for facilitating the gaseous exchange of CO_2 and O_2 during photosynthesis. The gas exchange function of the stomata also leads to the loss of plant water through transpiration.

10.3 Transport in Plants

10.3.1 Vascular Tissues and transport of materials

You have learnt that vascular plants or 'tracheophytes' have specialised tissue, termed xylem and phloem, for conducting water (plus solutes) and organic nutrients respectively. Let's discuss these tissues in detail.

10.3.1.1 Xylem

Xylem cells are elongated and connected end to end to form a tubular water-transport system throughout the plant, continuously replacing the large amount of water lost by transpiration, water that is essential for both photosynthesis and to maintain turgor pressure. The main kinds of xylem are tracheids and vessel elements.

a. Tracheids

Tracheids are elongated cells up to 80μm wide with secondary, lignified cell walls. When mature, tracheids are subject to loss of protoplast (nucleus and cytoplasm) and hence cell death, creating an open structure for water flow, retarded only by the thin cellulose barrier of the porous pits through which water flows from cell to cell. Functional tracheal conduits are surrounded by support and storage cells, including parenchyma, fibers and sclereids.

b. Vessel elements

Vessels are characteristic of the angiosperms, the most advanced and diverse group of plants. Vessels are specialized for efficient water conduction, reducing the costs of water loss by evapo-transpiration.

Vessels element are generally wider, shorter, thinner-walled, and less tapered than tracheids. Vessel elements are individual cells linked together end to end, forming long tubes or xylem vessels.

Water streams from element to element through perforated end walls. Water can also migrate laterally between neighboring vessels through pits.

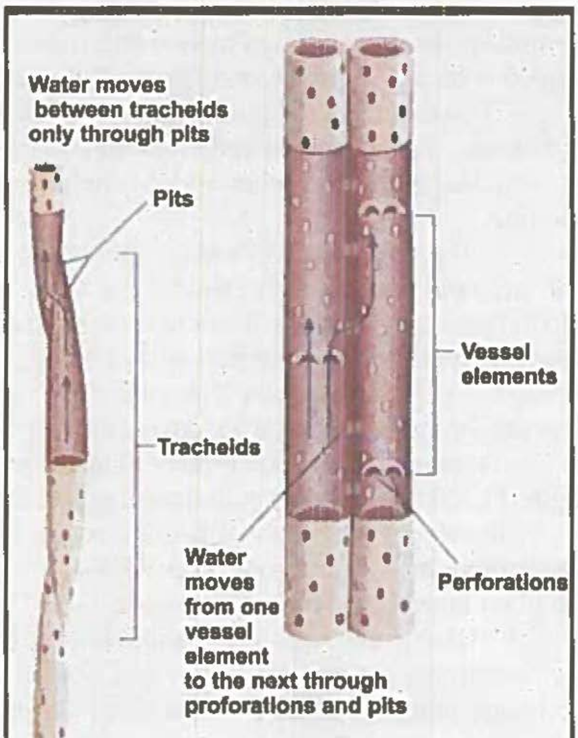


Fig: 10.2 Tracheids and vessel members of xylem tissue

10.3.1.2 Phloem

Organic solutes move through phloem which is generally found on the outer side of xylem tissues in plants. Phloem forms the inner bark. The cells of the phloem that transport the organic solutes through out the plant are the sieve tubes. Phloem is a complex tissue. It is present in all vascular plants. It consists of five different kinds of cells. Phloem parenchyma, phloem fibers, sieve tubes, companion cells and phloem ray cells.Out of these cells, the sieve tubes are especially adopted for the process of translocation.

a. Sieve tubes

Sieve tubes are elongated living cells, placed end to end with the walls consisting of cellulose. The end walls are perforated by a number of small pores. The perforated area of the end walls look very much like a sieve and is called **sieve plate**. The pores of the sieve plate are open channels which help in the translocation of solutes. Associated with almost every sieve tube is a thin walled elongated cell called companion cell.

b. Companion cell

Companion cell is living cell containing cytoplasm and elongated nucleus. The sieve tubes and the companion cells are in communication with each other by plasmodesmata. The companion cells supply energy to the sieve tube and help the sieve tubes in translocation.

The organic solutes from the mesophyll of leaf pass into the sieve tube through the **companion** cells via plasmodesmata. The companion cells are present in angiosperms but absent in gymnosperms and ferns.

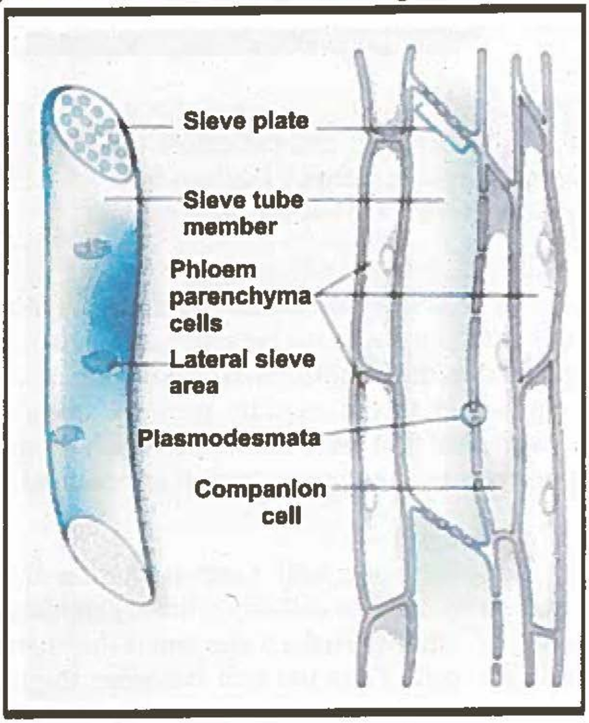


Fig: 10.3 Different kinds of Phloem cells

10.3.2 Water-status in plants

Water plays an important role in the life of plants. It is one of the factor used in photosynthesis.. The behavior of water with the respect to plant can be described by certain phenomena like water potential, osmotic potential, pressure potential etc.

a. Water potential

Molecules of water possess kinetic energy. Therefore, they are in constant motion from one place to another. Water potential is directly proportional to the concentration of water-molecules. Greater the concentration of water molecules in a system, greater is the kinetic energy of water molecules. This is called water potential. Pure water has maximum water potential. Water potential is represented by the symbol "Ψw' (ψ; pronounced /sai/ sigh). It is measured in kilopascal 'Kpa' one Kpa=1000 Pascal.

For Your Information

Blaise Pascal was a very influencial French mathematician and philosopher who contributed to many areas of mathematics.

Factor such as heat affect the water potential. Water potential plays an important role in plant physiology because it affects absorption of water by the root hairs and its onward transport in the plant.

b. Solute potential or osmotic potential

The solute potential or osmotic potential is a measure of the change in the water potential due to the presence of solute molecules. Thus the rate of osmosis is depended on the osmotic potential difference along the two sides. Osmotic potential is equivalent to the osmotic pressure because it is this potential difference in between a solvent and its solution which produces the pressure. Solute potential is represented by the symbol "Ψ s'. It is measured in 'Kpa' (kilopascal).

c. Pressure potential

Pressure potential is representation of turgor pressure developed as a result of endosmosis by the cell-sap. This is just like the pumping of water from one place to another. Thus when the water enters the plant cells by osmosis, pressure is built up inside the cell. Thus the cell becomes turgid, or we may say that the pressure potential increases. It is shown by "Ψp'. Pressure potential plays a vital role in the erectness of soft plants and also in maintaining their shape.

10.3.3 Movement of water through roots

Water and minerals from the soil to the xylem move by the way of appoplast, sympalst and through vacuoles. Water from the soil is absorbed by the root hairs due to their high permeability.

The cell walls of epidermal cells of the roots are freely permeable to water and minerals. The cell membrane however is partially permeable to some substances in the solution. The water which enters the epidermal cells of the root passes through the cortex, endodermis, pericycle and finally to the xylem-cells through the paths which are described below.

a. Apoplast Pathway

Water from the soil is absorbed by the root hairs, from where it moves inwards across the cortex through a system of interconnecting cell-walls and inter cellular spaces and reach the endoderm and pericycle. Water is then poured into the xylem. This whole nonliving water path is called apoplast pathway.

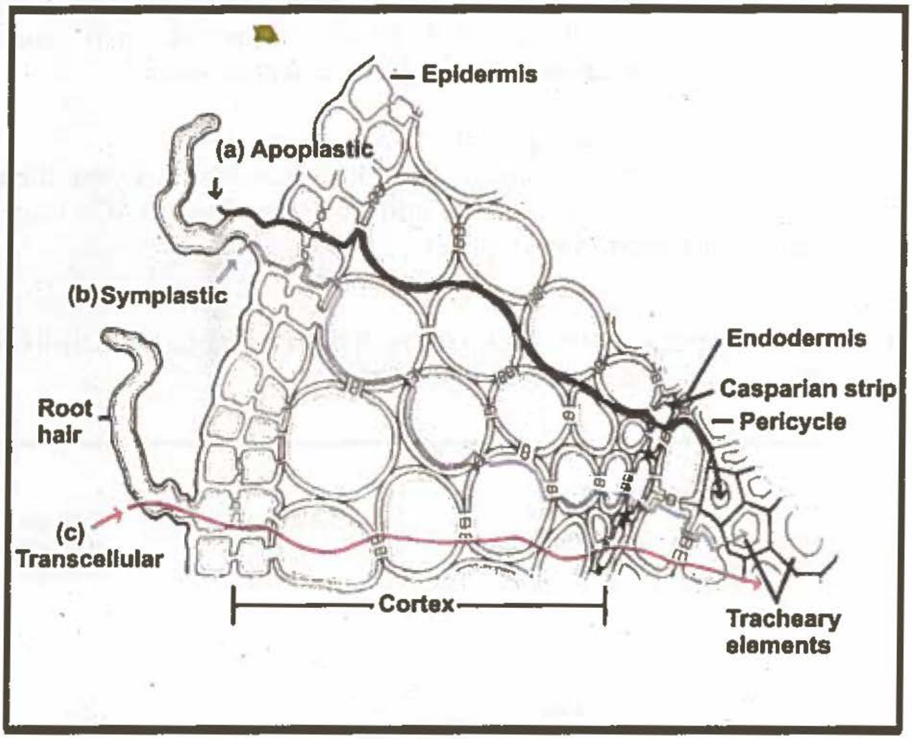


Fig: 10.4 Three different pathways of water movement through roots. Apoplast pathway shown by black line, symplast pathway shown by blue line, transcellular pathway by red line.

b. Symplast pathway

Water not only translocates along the nonliving cell walls and intercellular spaces but also moves inwards across the living cortical cells by the process of osmosis.

Such a living medium transport of water is termed as symplast pathway. It is the system of intercellular protoplasts (cytoplasm of the neighbouring cells) in the cells of roots. In the cells of the roots, both the cell membrane and cytoplasm act as one partially permeable membrane.

c. Vacuolar or transcellular pathway

The attached cells have interconnected vacuoles. Cells and the vacuoles are connected with one another by the plasmodesmata. Plasmodesmata are the cytoplasmic strands which extend through the pores in the adjacent cell walls). In this pathway water moves from vacuole to vacuole. The plasmodesmata act as a source of water movement across the cells towards the xylem. This is also symplast pathway but specially the vacuolar pathway. Whatever may be the path but water is absorbed by the roots from the soil and is transferred to the xylem of roots, stem and consequently the leaf-xylem and mesophyll which are the main part generating enough water potential for hundreds of feet high movement of water.

10.3.4 Water Movement in Xylem through TACT Mechanism

Four important forces combine to transport water solutions from the roots, through the xylem elements in the stem, and into the leaves. These TACT forces are: transpiration, adhesion, cohesion and tension.

a. Transpiration

It involves the pulling of water up through the xylem of a plant utilizing the energy of evaporation and the tensile strength of water.

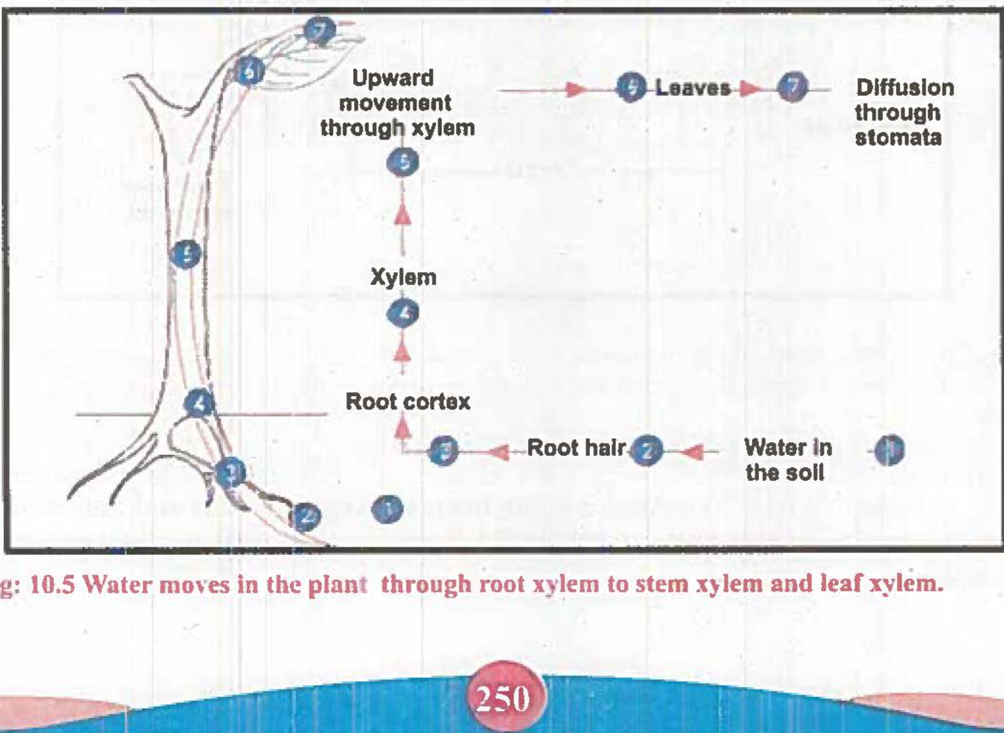


Fig: 10.5 Water moves in the plant through root xylem to stem xylem and leaf xylem.

b. Adhesion

It is the attractive force between water molecules and other substances. Because both water and cellulose are polar molecules there is a strong attraction for water within the hollow capillaries of the xylem.

c. Cohesion

It is the attractive force between molecules of the same substance. Water has an unusually high cohesive force due to the hydrogen bondings. It is estimated that water's cohesive force within xylem give it a tensile strength equivalent to that of a steel wire of similar diameter.

A combination of adhesion, cohesion, and surface tension allow water to climb the walls of small diameter tubes like xylem. This is called capillary action. The U shaped surface formed by water as it climbs the walls of the tube is called a meniscus

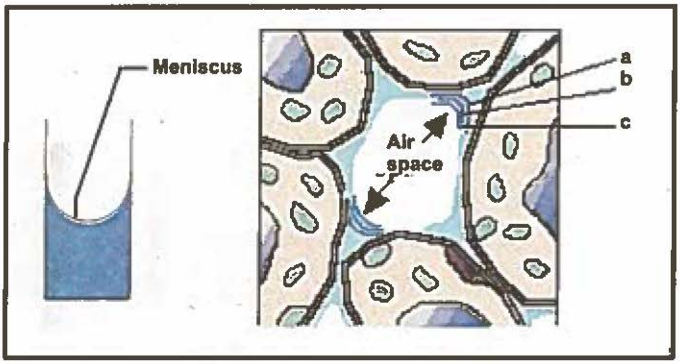


Fig: 10.6 Meniscus formation in the xylem

d. Tension

It can be thought of as a stress placed on an object by a pulling force. This pulling force is created by the surface tension which develops in the leaf's air spaces.

Tension is a negative pressure - a force that pulls water from locations where the water potential is greater. The bulk flow of water to the top of a plant is driven by solar energy since evaporation from leaves is responsible for transpiration pull.

10.3.5 Mechanism of Opening and Closing of Stomata

Mechanism of opening and closing of stomata can be studied by the following most acceptable theories.

1. Starch Sugar Theory

According to this hypothesis photosynthesis occurs in light by absorbing carbondioxide which lowers the H^+ ion of cell sap and pH of guard cell is increased. High pH favours the activity of enzyme phosphorylase which converts starch into glucose and phosphate. It dissolves in the medium and increases the concentration of cell sap.

This causes an increase in the osmotic pressure of guard cells and its diffusion pressure deficit (DPD) also increases which results in the movement of water into the guard cells from surrounding cells. Guard cells become turgid and swell. Thus the stomata open.

During dark, the level of carbondioxide in substomatal cavity is increased which results in the decrease in the pH of guard cells. At low pH glucose is converted back to starch in the presence of enzyme phosphorylase. Synthesis of starch leads to the dilution of cell sap by consuming its dissolved glucose molecule. Thus osmotic pressure of cell sap is decreased and its DPD (diffusion pressure deficit) is decreased. The turgid cells lose water to surrounding cells and becomes flaccid and stomata closes.

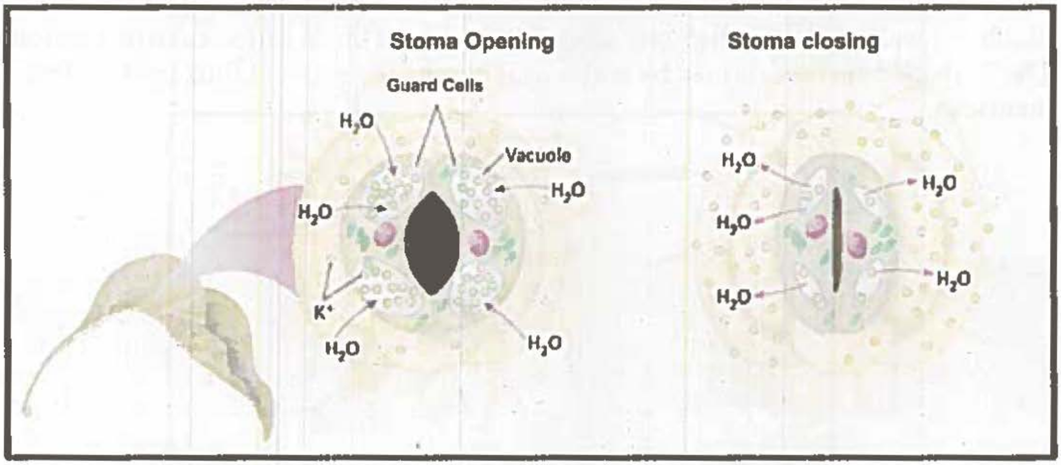


Fig: 10.7 Mechanism of stomatal opening and closing

2. Theory of K^+ ion transport

In the presence of light starch is converted into phosphorylated hexoses and then to phosphoenol pyruvic acid which combines with carbondioxide to produce malic acid. Malic acid dissociate into malate anion and H^+ ion in the guard cell. H^+ ions are transported to epidermal cells and K^+ ions are taken into the guard cells in exchange of H^+ ions. Increased concentraton of K^+ ions and malate ions in the vacuole of guard cells causes sufficient osmotic pressure to absorb water from surrounding cells. It results in the opening of stomata.

In the dark carbondioxide concentration is increased in the substomatal cavity which prevents proton gradient across the protoplasmic membrane in guard cells. As a result active transport of K^+ ions into guard cells ceases. As soon as the pH of guard cells decreases the abscissic acid inhibits K^+ ion uptake by changing the diffusion and permeability of guard cells. Malate ion in the guard cell cytoplasm combine with H^+ ion to produce malic acid. These changes cause reversal of concentration movement.

So the K^+ ion is transported out of guard cells into the surrounding epidermal cells. The osmotic pressure of guard cell is decreased which results in the movement of water from guard cells to surrounding cells and guard cells becomes flaccid and stomata closes.

10.3.6 Translocation of organic solutes

Green leaves are the photosynthetic machinery of the plant. These green leaves are regarded as **"source of assimilates "** because these are the sites of production of sugar during the process of photosynthesis. This sugar is converted into sucrose which is transported out of the leaf to the stem and then upwards to the buds ,fruits or seeds and downwards to the roots or the underground stems.

The buds, seeds, fruits, roots and the underground stems are together called **"sinks of assimilates"**. They utilize or store sugar. This transport of organic solutes from the source of assimilates to the sinks of assimilates is called translocation of organic solutes.

a. Pressure flow mechanism: (Mechanism of translocation of organic solutes)

Food, primarily sucrose is transported by the vascular tissue called phloem from a source to a sink. Unlike transpiration's one-way flow of water sap, food in phloem sap can be transported in any direction needed so long as there is a source of sugar and a sink able to use, store or remove the sugar. The source and sink may be reversed depending on the season, or the plant's needs.

Sugar stored in roots may be mobilized to become a source of food in the early spring when the buds of trees, the sink, need energy for growth and development of the photosynthetic apparatus.

Phloem sap is mainly water and sucrose, but other sugars, hormones and amino acids are also transported. The movement of such substances in the plant is called **translocation.**

b. The Pressure flow or mass flow hypothesis

The accepted mechanism needed for the translocation of sugars from source to sink is called the pressure flow hypothesis. As glucose is made at the source it is converted to sucrose (a dissacharide).

The sugar is then moved into companion cells and into the living phloem sieve tubes by active transport. This process of loading at the source produces a hypertonic condition in the phloem. Water in the adjacent xylem moves into the phloem by osmosis. As osmotic pressure builds the phloem sap will move to areas of lower pressure.

At the sink osmotic pressure must be reduced. Again active transport is necessary to move the sucrose out of the pholem sap and into the cells which will use the sugar -- converting it into energy, starch, or cellulose.

As sugars are removed osmotic pressure decreases and water moves out of the phloem.

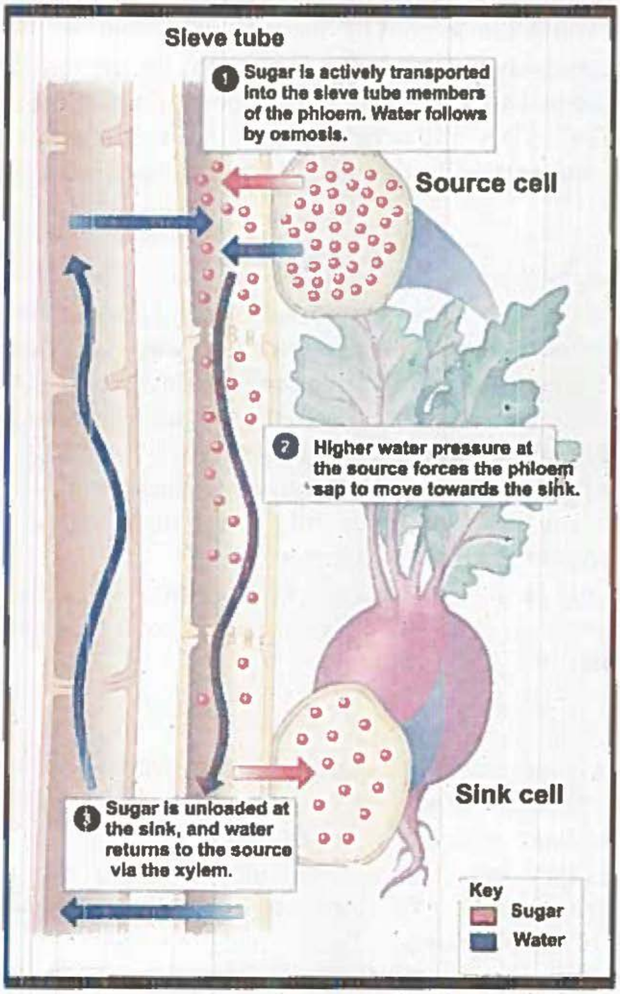


Fig: 10.8 Steps in the Pressure Flow Hypothesis

10.4 Homeostasis in Plants

Plants are present in diverse environmental conditions. In order to survive plants have to adopt various measures. Such measures are part of the homeostasis mechanism. Homeostasis is the ability of living organisms to maintain or nearly maintain constant internal conditions. It provides the organism with a certain degree of independence from variations in the external environmental conditions. Homeostasis does not mean to keep a fixed internal environment as changes with in a specific range are necessary for normal body functions. It refers to the fact that the composition of the tissue fluid in the body is kept within narrow limits. Most of plant mechanisms are related with the presence or absence of water. Osmoregulation or osmotic regulation is the homeostasis of water i.e. the control of gain or loss of water and dissolved salts. Plants are confronted with different situations in terms of their water availability.

Water moves readily across cell membranes through special protein-lined channels, and if the total concentration of all dissolved solutes is not equal on both sides, there will be net movement of water molecules into or out of the cell. Whether there is net movement of water into or out of the cell and which direction it moves depends on whether the cell's environment is isotonic, hypotonic, or hypertonic.

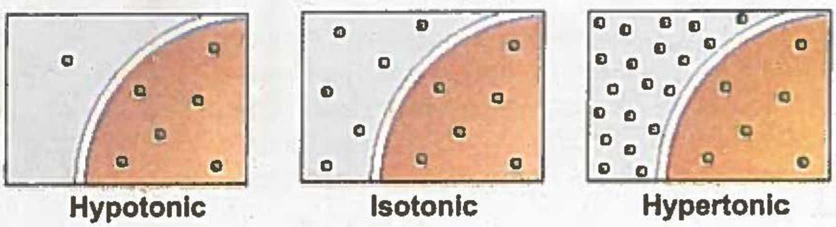


Fig: 10.9 Osmoregulation in different conditions.

a. Isotonic

When two environments are isotonic, the total molar concentration of dissolved solutes is the same in both of them. When cells are in isotonic solution, movement of water out of the cell is exactly balanced by movement of water into the cell.

b. Hypotonic

In a hypotonic solution the total molar concentration of all dissolved solute particles is less than that of another solution or less than that of a cell. If concentrations of dissolved solutes are less outside the cell than inside, the concentration of water outside is correspondingly greater. When a cell is exposed to such hypotonic conditions, there is net water movement into the cell. Cells without walls will swell and may burst (lyse) if excess water is not removed from the cell. Cells with walls often benefit from the turgor pressure that develops in hypotonic environments.

c. Hypertonic

A hypertonic solution is a particular type of solution that has a greater concentration of solutes on the outside of a cell when compared with the inside of a cell.

10.4.1 Osmoregulation in Plants

Of all the environmental factors that determine the vegetation of a habitat, water is considered to be the most important. Osmoregulation has enabled the plants to be distributed in wide range of habitat. Hence according to the amount of water available, plants are classified into four main groups:

Fig: 10.10 Hydrilla

a. Hydrophytes

Hydrophytes grow in the water or in wet and damp places such as ponds, streams etc. In these plants the absorption of water takes place over the whole surface of the plant, root hair being absent. The surface area of the leaves is large enough with plenty of stomata (in partly submerged hydrophytes). These features favour excessive transpiration. e.g. *Hydrilla, Vallisneria, Potamogeton* etc.

Fig: 10.11 Brassica

b Mesophytes

Mesophytes are the ordinary land plants, which grow under average condition of moisture. In limited supply of water, they close the stomata to prevent loss of water. However, in abundant supply of water, they keep the stomata open to transpire the water rapidly, e.g. citrus, brassica, pea, peach and rose etc.

c. Xerophytes

Xerophytes are desert plants which grow in dry, hot and sandy places with scanty rainfall. They have long roots to absorb water. The stem contains water storage tissue. The leaves are modified into spines or thorns to reduce evaporation of water. Hairs on the stem and leaves retard transpiration. The leaves are covered with thick cuticle. The stomata are usually very much reduced in number and sunken below the epidermis. Examples are *Cactus, Opuntia, Aloe, Ruscus, Acacia, Calotropis* and *Zizyphus* etc.

Fig: 10.12 The thick stems of *cacti* store water and carry out photosynthesis. Their leaves are reduced to spines, conserve water while providing protection.

d. Halophytes

Halophytes can grow in a soil containing large percentage of common salt and therefore occur on seashores forming special type of vegetation called mangrove. They are salt tolerators and not salt lovers. Although there is plenty of water in the soil, water absorption is fairly difficult due to abundance of salts in the soil water. Hence they show physiological drought and show xerophytic characters. The stems contain well developed water storage tissues. The leaves are covered with thick cuticle to prevent evaporation of water.e.g *Salsola* (saltwort) and *Rhizophora*.

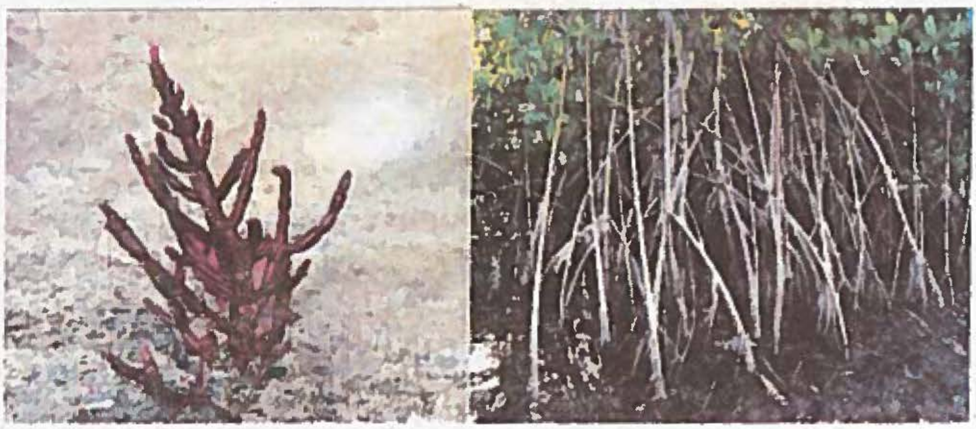


Fig:10.13 a. *Salsola* (saltwort) b. *Rhizophora*

a. *Salsola* (saltwort)is a halophyte (a salt-tolerant plant) that typically grows in coastal regions and can be irrigated with salt water.

b. *Rhizophora* is a dominate in mangrove forests around much of the world's tropics.

10.4.2 Adaptations of plants to low and high temperature

Temperature is one of the most important ecological factors. Temperature for a plant may be maximum, minimum, or optimum. Metabolism becomes slow at both low temperature and high temperature. Extremely high temperature causes heat injury in plants while the freezing temperature causes ice crystal formation. Both these effects are harmful to plants.

These variations in temperature range require the plants to adjust themselves to the environment and this is adaptation. Plants possess some morphological and anatomical structures to counter very high or very low temperature.

Some of them are as under:

1. Low temperature

Plants growing in low temperatures may suffer from ill-effects. To mange low temperature, they possess well-developed bark for protection and short life cycles. Such plants bring changes in the composition of solutes in the cell to prevent ice crystal formation. The leaves and stems are hard and can withstand low temperature. Most of them possess scale leaves and the rate of transpiration is low to retard cooling.

2. High temperature

The protoplasm, enzymes and proteins may denature at high temperature so, the plants use structures and mechanisms to adjust themselves to such condition. Plants absorb maximum water in short rainy season. The water is stored for carrying out various metabolic activities. Some plants produce an extensive branching root system, so they can absorb even the little available water. The extensive spreading of upper parts of the plant reduces the evaporation of water from the soil surface. The leaves of the plants contain thick cuticle and in some cases, an additional waxy layer. Such adaptations protect the plants from the strong rays of the sun and reduce water loss from the plant body.

The sunken stomata regulate transpiration and stems of some plants are succulent with large vacuoles to store water for the cell metabolism. In many plants leaves are modified into spines to reduce transpiration.

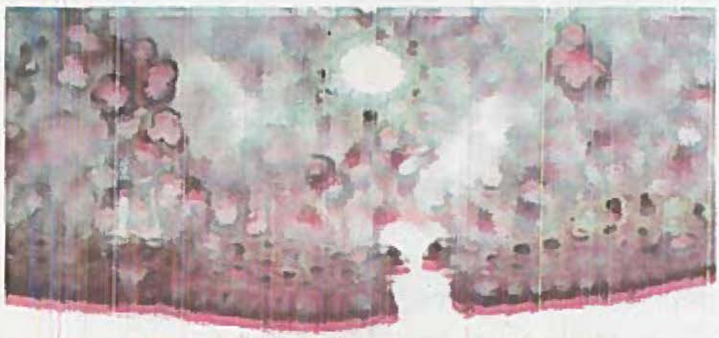


Fig: 10.14 Part of a Pine needle showing the hypodermis and sunken stomata.

Observing, Analyzing and Interpreting

Interpret the adaptive differences through survey of xerophytic, mesophytic and hydrophytic plants. Illustrate the structure and position of stomata in xerophytic, mesophytic and hydrophytic plants.

10.5 Support in plants

Non-lignified plant tissues are supported by the pressure of cell contents against the (primary) cell walls of their tissues. This **turgor** pressure is caused by the uptake of water by the cytoplasm of the cells so that pressure is exerted at the plasma membrane on the cell wall. Herbaceous plant does not form a persistent woody stem. Herbaceous plants are often known for their attractive flowers or foliage.

It is a common observation that plants cannot remain upright if their hard tissue such as fibre is damaged or they lose turgor. Support to the plants is provided by the mechanical tissues, which consist of collenchyma and sclerenchyma. Non-woody plants are supported by turgidity (water pressure) of parenchymatous cells. These plants remain erect and firm because of the pressure within these cells. During the period of drought, the tissues of such plants lose water and result in wilting.

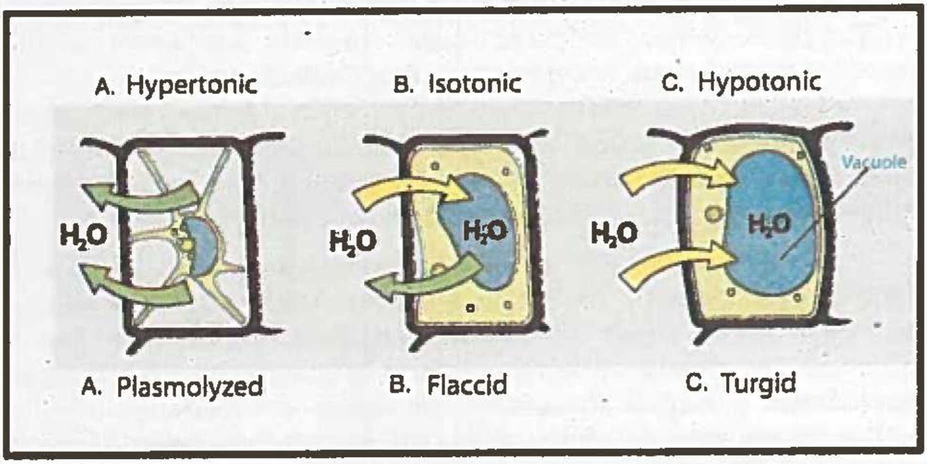


Fig: 10.15 Turgor pressure in different environments

Plant cells are surrounded by rigid cell walls. When plant cells are exposed to hypotonic environments, water rushes into the cell, and the cell swells, but is kept from breaking by the rigid wall layer. The pressure of the cell pushing against the wall is called turgor pressure, and is the desired state for most plant tissues. For instance, placing a wilted celery stalk or lettuce leaf in a hypotonic environment of pure water, will often revive the leaf by inducing turgor in the plant cells.

10.5.1 Structure of supporting tissues in plants

The development of stable supporting elements has been an important prerequisite for the evolution of large terrestrial organisms. Animals have endo- or exoskeletons that are similar in function to the woody stems or trunks of plants. The architectural design of the plant is very complex.

Thin petioles carry heavy and flat laminas, stems support leaves, flowers and fruits. All plant organs are exposed to mechanical strains. Extensive specialized supporting tissues exist only in vascular plants. Vascular plants have up to three main types of supporting tissue:

1. Collenchyma
2. Sclerenchyma
3. Vascular tissue

1. Collenchyma

The name collenchyma derives from the Greek word "kolla", meaning "glue", which refers to the thick, glistening appearance of the walls in fresh tissues. The collenchyma is the typical supporting tissue of the primary plant body and growing plant parts.

Collenchyma is characteristically found in leaves and elongating stems. In leaves, it appears as strands, often located above and below major veins, as well as in petioles and sometimes leaf blade margins. In stems, it appears as a hollow cylinder around vascular tissues, or as peripheral longitudinal strands.

Collenchyma cells have unequally thickened primary walls, especially when observed in cross-sectional view. The different thickness patterns of the wall is a characteristic feature formed during elongation. There are four primary types of collenchyma: angular, annular, lamellar (or plate), and lacunar.

Collenchyma is a living tissue composed of elongated cells with thick non-lignified primary walls. Such cells are most closely aligned physiologically with parenchyma cells. Where collenchyma and parenchyma cells are found adjacent to each other, they frequently intergrade through transitional cells. The resemblance to parenchyma is further stressed by the common occurrence of chloroplasts in collenchyma and by the ability of this tissue to undergo reversible changes in wall thickness, and to engage in meristematic activities. Thus, it is entirely appropriate to consider these two cell types in the same unit of study.

2. Sclerenchyma

The other true supporting tissue is the sclerenchyma. The term "sclerenchyma" is derived from the Greek "scleros", meaning "hard". It is their hard, thick walls that make sclerenchyma cells important strengthening and supporting elements in plant parts that have ceased elongation.

Two groups of sclerenchyma cells exist: fibres and sclereids. Their walls consist of cellulose or lignin. Sclerenchyma cells are the principal supporting cells in plant parts that have ceased elongation. Sclerenchyma fibres are of great economical importance, since they constitute the source material for many fabrics (flax, hemp, jute, ramie).

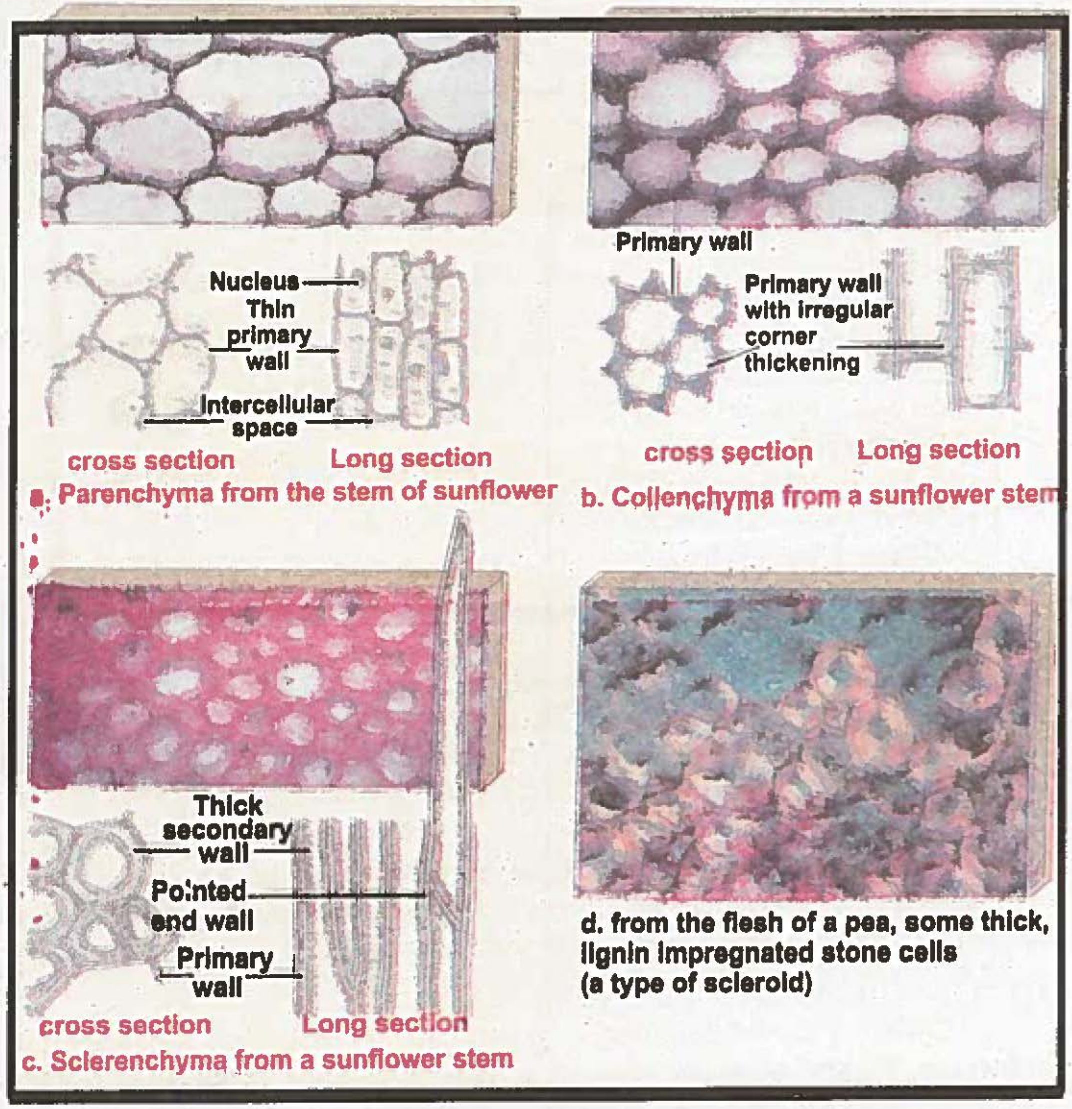


Fig: 10.16 Example of ground tissue, which make up the bulk of the plant body. The most common types are parenchyma, collenchyma and sclerenchyma (the stone cell in 'd' are a specialized form of sclerenchyma).

The difference between fibres and sclereids is not always clear. Transitions do exist, sometimes even within one and the same plant. Fibres arise from meristematic tissues. Cambium and procambium are their main centers of production. They are often associated with the xylem of the vascular bundles. The fibres of the xylem are always lignified. Fibres that do not belong to the xylem are bast (outside the ring of cambium).

For Your Information

Fibres are generally long, slender, so-called prosenchymatous cells, usually occuring in strands or bundles. Such bundles or the totality of a stem's bundles are colloquially called fibres. Their high load-bearing capacity and the ease with which they can be processed has since antiquity made them the source material for a number of things, like ropes, fabrics or mattresses. The fibres of flax *(Linum usitatissimum)* have been known in Europe and Egypt since more than 3000 years, those of hemp *(Canabis sativa)* in China for just as long. These fibres, and those of jute *(Corchorus capsularis)* and ramie (*Boehmeria nivea*, a nettle), are extremely soft and elastic and are especially well suited for the processing to textiles. Their principal cell wall material is cellulose.

Sclereids are variable in shape. The cells can be isodiametric, prosenchymatic, forked or branched. They can be grouped into bundles, can form complete tubes located at the periphery or can occur as single cells or small groups of cells within parenchyma tissues. But compared with most fibres sclereids are relatively short.

Characteristic examples are the **stone cells** (called stone cells because of their hardness). The shell of many seeds like those of nuts as well as the stones of drupes like cherries or plums are made up from sclereids.

10.6 Growth and Development in Plants

Growth and development in plants are two associated physiological processes, following each other in quick succession. They lead towards morphologically distinct tissues and organs. Growth is defined as increase in number and size of cells. Three phases of growth can be identified in the. . growing root and stem. They are: (a) Phase of cell division (b) Phase of cell elongation (c) Phase of cell maturation and differentiation.

The flowering plants (**angiosperms**) go through a phase of **vegetative growth** — producing more stems and leaves — and a flowering phase where they produce the organs for sexual reproduction. Meristems are undifferentiated, perpetually juvenile plant tissues which are capable of dividing mitotically, producing plant growth.

Merstematic tissues are of two main kinds;

1. Apical meristem
2. Lateral meristem

1. Apical Meristems

Apical meristems are areas of actively dividing cells at the tips of all roots and shoots. The apical meristem gives rise to the three primary meristems (protoderm, ground meristem and procambium) and these in turn produce all tissues. As in roots, the outermost layer of a primary shoot is the epidermis, which arises from the protoderm. The epidermis may contain stomata or lenticels for gas exchange, or may have a waxy or hairy surface to prevent dessication. The shoot cortex arises from ground meristem. The primary vascular tissues, the primary phloem, vascular cambium and primary xylem, arise from the procambium. These three tissues are organized into separate vascular bundles. Finally, the innermost shoot tissue is the pith. It is produced by the central ground meristem, and functions for a short period as a storage tissue as shown in the following figure.

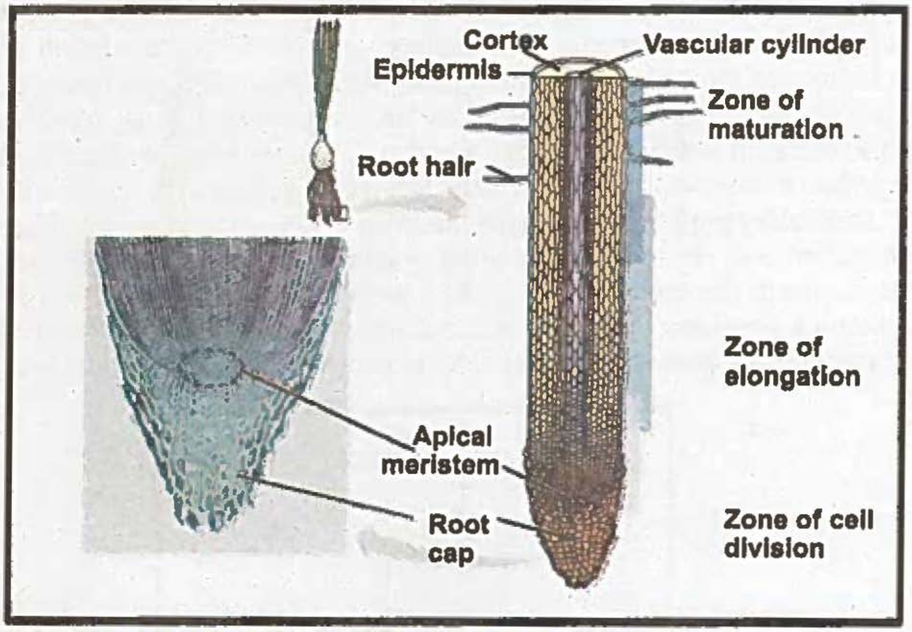


Fig: 10.17 Root tip showing different phases of growth.

Being present at the tips of root and shoot, apical meristems help in increasing the length of the plant body. This elongation is called primary growth. All vascular plants, whether herbaceous or woody, undergo primary growth. Production of lateral branches leaves and flowers also occur by primary growth. Primary growth is found in most monocots and some herbaceous annual dicots.

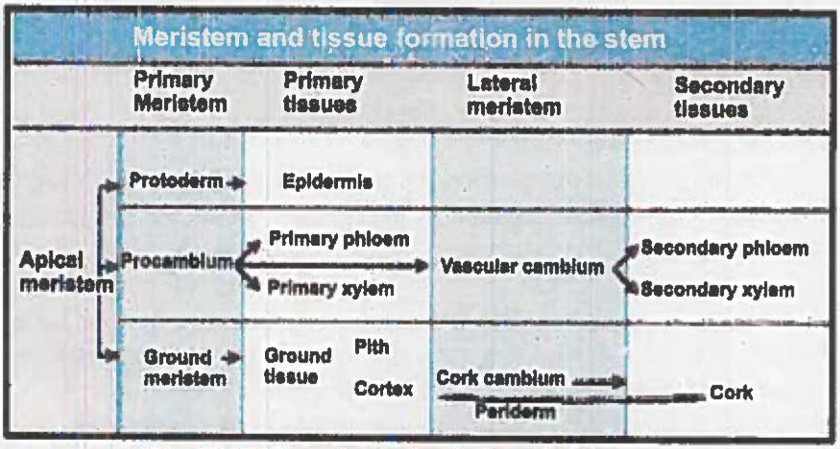


Fig: 10.18 Flow chart of apical meristem.

2. Lateral Meristems

Lateral meristems are the cylinders of dividing cells found in gymnosperms and dicots. They are concerned with secondary growth or increase in thickness of the plant. There are two types of lateral meristems—vascular cambium and cork cambium. Vascular cambium produces secondary vascular tissues, which conduct water and nutrients and provide added support. Cork cambium produces cork cells, which protect the stem and root from water loss, pathogens, and herbivorous insects.

Secondary growth occurs in perennial dicots and gymnosperms. This type of growth, called also secondary thickening or lateral growth, arises from secondary meristems. From the procambium in the vascular bundles secondary cambium is formed which produces secondary phloem and secondary xylem. In some species cork cambium that makes cork tissue develops from parenchymatous cells in the cortex.

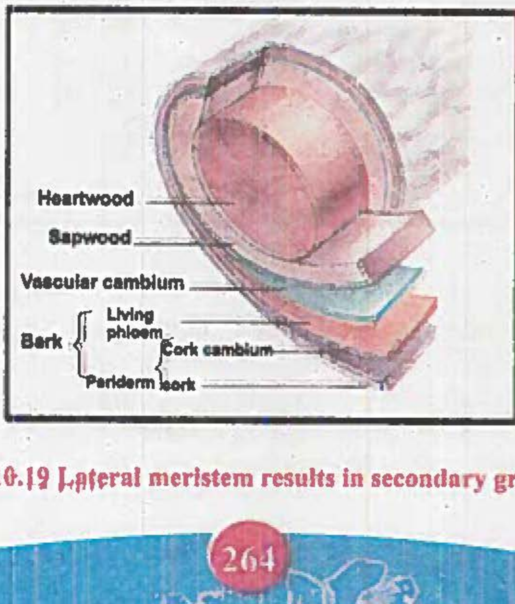


Fig: 10.19 Lateral meristem results in secondary growth.

10.6.1 Growth Correlation

In a growing plant, the development of every organ is affected by the physiological processes occurring in some other organ e.g. the vegetative growth of many plants is highly affected during fruiting. Similarly, the formation of flower buds and flowers may be controlled by the processes taking place in leaves. Such reciprocal relationship for growth among the different organs of a plant is called growth correlation. The correlation may be inhibitory or compensatory.

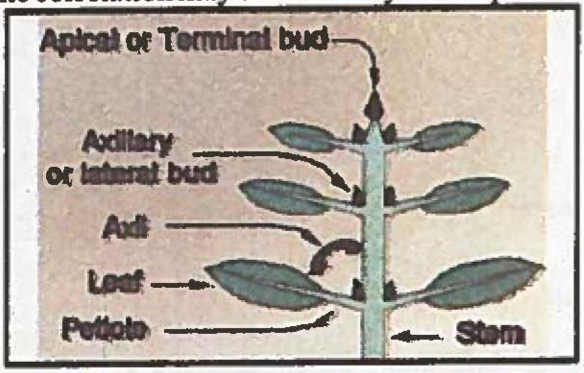


Fig: 10.20 A young stem showing apical and axillary buds

1. Inhibitory correlation (Apical dominance)

The inhibition or control of lateral buds to develop by the activity of apical bud is called inhibitory correlation or apical dominance. This is the most important and the most common example of correlation in plants. The active apex of the shoot controls the development of lateral buds. This is proved by the fact that if the apical bud is cut off, then one or more of the axillary buds grow out and exert inhibitory effect on the buds below. Apical dominance may be complete or incomplete.

(a) Complete apical dominance

In complete apical dominance only the main shoot grows and the lateral buds are not allowed to developed, as in sunflower the growth of lateral bud is completely inhibited.

(b) Incomplete apical dominance

In this case the apical dominance is weak because it cannot control the development of lateral buds, which grow out to form a bushy appearance e.g. in tomato.

2. Compensatory Correlation

When the removal of one part enhance (increase) the growth of other part is called compensatory correlation.Example: Thinning of fruits can cause the remaining fruits to grow larger in size. In *Chrysanthemum* removal of all buds except one results in the development of one large single flower.

10.6.2 Annual rings

Every tree keeps its own diary of climatic changes or other events that affect its growth. Each year a page is added which records whether that was a lean year or a fat one. Each year, beneath the bark, the tree adds a layer of wood to its trunk. When conditions are ideal, the layer is thick. When there is a severe drought, or a plague of insects that destroy most of its leaves in early summer, or some other trouble, the layer will be thin. If the tree is cut down with a saw, those layers appear on the stump as a series of concentric rings called Annual Rings or Tree Rings. A tree ring is simply a layer of wood produced during one tree's growing season. Each tree ring marks a line between the dark late wood that grew at the end of the previous year and the relatively pale early wood that grew at the start of this year. One annual ring is composed of a ring of early wood and a ring of late wood.

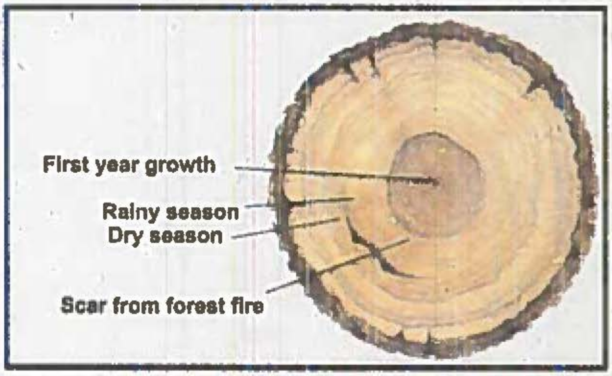


Fig:10.21 Annual Rings or Tree Rings are layers that appear on the stump as a series of concentric rings.

For Your Information

One of the most accurate way to estimate tree age is to count the annual rings of wood growth. For trees that are dead and have been cut down, you can count the rings on the stump. This provides an accurate estimate of its age.

The growth occurs in the cambium. In spring, the cambium begins dividing. This creates new tissue and increases the diameter of the tree at two places:

1. **Outside the cambium:**

The outer cells become part of the phloem. The phloem carries food produced in the leaves to the branches, trunk, and roots. Some of the phloem dies each year and becomes part of the outer bark.

2. **Inside the cambium:**

The inner cells become part of the xylem. These cells contribute most of a tree's growth in diameter. The xylem carries water and nutrients from the roots to the leaves. These cells show the most annual variation:

When a tree grows quickly, the xylem cells are large with thin walls. This early wood or springwood is the lighter-colored part of a tree ring. In late summer, growth slows; the walls of the xylem cells are thicker.

This late wood or summerwood is the darker-colored part of a tree ring. When conditions encourage growth, a tree adds extra tissue and produces a thick ring. In a discouraging year, growth is slowed and the tree produces a thin ring.

10. 7 Growth Responses in Plants

Plants show growth responses by releasing certain chemicals or by showing differential growth rate or movement.

10.7.1 Plant Growth Substances

Hormones of plants are referred as Phyto Hormones. Phyto Hormones are organic substances which are naturally produced in plants; control the growth or other physiological functions, at a sight remote from its place of production and active in extreme minute quantities. There are five major growth hormones namely auxins, gibberellins, cytokinins, abscisic acid and ethylene.

1. Auxins

Auxin is a Greek word, which means "to increase". Naturally occurring auxin is a hormone that is produced in the apical meristems of shoots and the tips of coleoptiles. Indole acetic acid with other related compounds are collectively called as auxin. Auxins control and regulate many physiological processes. Auxin travels by diffusion toward the base of the plant, where it controls the lengthening of the shoot and the coleoptile, chiefly by promoting cell elongation.

Auxin also plays a role in differentiation of vascular tissue and initiates cell division in the vascular cambium. It often inhibits growth in lateral buds, thus maintaining apical dominance. The same quantity of auxin that promotes growth in the stem inhibits growth in the main root system.

2 Gibberellins

The gibberellins were first isolated from a parasitic fungus that causes abnormal growth in rice seedlings. They were subsequently found to be natural growth hormones present in many plants. The most dramatic effects of gibberellins are seen in dwarf plants, in which the application of gibberellins restores normal growth, and in plants with a rosette form of growth, in which gibberellins cause bolting. Gibberellins cause seed germination in grasses. In the barley seed, the embryo releases gibberellins that cause the aleurone layer of the endosperm to produce several enzymes, including alpha-amylase, which breaks down the starch stored in the endosperm, releasing sugar. The sugar nourishes the embryo and promotes the germination of the seed.

It can break the dormancy of the seed and cancels the effects of the inhibitory substances. In apples and grapes the exogenous application causes more fruit set. Gibberillins promote flowering, helps in growing seedless grapes and improves storage life of banana etc.

3. Cytokinins

The cytokinins were first discovered as a consequence of their capacity to promote cell division and bud formation in cultures of plant tissues. They are chemically related to certain components of nucleic acids. Cytokinins can also act along with auxin to cause cell division in plant tissue culture. In tobacco pith cultures, a high concentration of auxin promotes root formation, while a high concentration of cytokinins promotes bud formation. In intact plants, cytokinins promote the growth of lateral buds, acting in opposition to the effects of auxin. Cytokinins prevent senescence in leaves by stimulating protein synthesis.

4. Abscisic Acid (ABA)

After the discovery of auxins, plant physiologists suspected a dormancy causing chemical in plants. At last a substance that promotes abscission of cotton fruit was purified and was called "abscision II". At the same time a substance was obtained from *Bitula pubescence*, which promoted bud dormancy and was called 'dormin', similar to abscision II on chemical analysis. The abscision II was later named "abscisic acid" due to its abscision character and acidic nature.

Abscisic acid causes bud dormancy and seed dormancy. It inhibits active growth of seedling flowering in long day plants and promotes abscision. During stress conditions (water deficiency or drought) the concentration of abscisic acid increases which causes stomata to close and facilitates influx of water into the roots. Therefore abscisic acid is also called stress hormone that helps plant cope with adverse conditions.

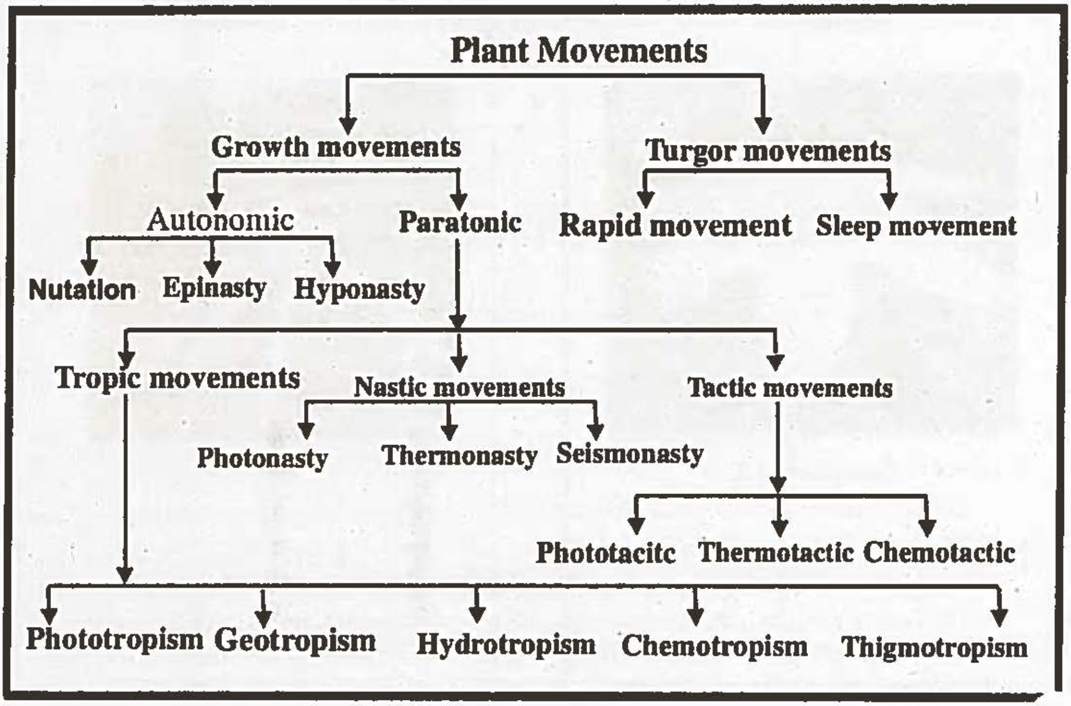
5. Ethylene

Ethylene, a gaseous hormone diffuses through the plant in air spaces It inhibits root growth and development of axillary buds when present in high concentration. Ethylene also stimulates fruit ripening and induces several aspects of senescence in plant cells and organs. The mechanism of leaf abscission involve decrease auxin and increase ethylene production.

10.7.2 Plant Movements

Plant movements are usually too slow for the direct observation but the results are easily noticed e.g. the closing and opening of flowers, unfolding of buds, bending towards light, twining of tendrils, locomotion of *Chlamydomonas* and the gametes of algae, bryophytes and pteridophytes etc.

Generally movement of plant parts can be classified according to the mechanism involved. Plants movements are classified into two major types; turgor movements and growth movements, rest of the classification of plant movements is as under.



1. Turgor Movement

Turgor movements are due to the differential changes in turgor and size of the cells as a result of the gain or loss of water and are easily reversible. The effective cells are often different from ordinary cells and may be concentrated in certain areas The rolling of leaves of many grasses in dry weather is caused by loss of water from the bulli-form cells, which form longitudinal rows in epidermis. The dropping folding up in some plants at night are caused by turgor changes in the cells of the pulvinus which are present at the base of the leaf or leaflet.

The pulvinus is composed of parenchyma cells with large intercellular spaces and a central strand of vascular tissue. The water passes into or out of these cells more freely on one side of the pulvinus than on the other side. This unequal movement of water causes unequal enlargement or shrinkage (turgor response) and a consequent movement of the petiole and leaf blade.

Turgor movement may be: (a) rapid movements (b) sleep movements..

a. Rapid Movement

When the leaves of Mimosa or "touch me not" are touched, the lower cells of the pulvinus loose their turgidity. The leaves bend downward. After some time the leaves regain their turgidity and thus become erect.

Fig: 10.22 Response of *Mimosa pudica* to shock. Left (before) and right (after)

b. Sleep Movements

Some plants of family leguminoceae such as bean plants lower their leaves in the evening and raise them in the morning. These are called sleep movements. The sleep movements are due to daily changes in the turgor pressure in the pulvinus. When the turgor pressure on the lower side of the pulvinus increases, the leaves rise and when decreases, the leaves lower. This is called sleep movement.

2. Growth Movements

Growth movements may be self controlled or induced by the plant organs by external stimuli. They are irreversible movements, caused due to unequal growth on both sides of the plant organs like roots, stems, buds and tendrils. On this basis the growth movements are classified into:

a.. Autonomic b. Paratonic

a. Autonomic Movements

Movement in which the whole plant shifts from one place to another is called locomotion. These are spontaneous movements or self control movements e.g. certain algae such as *Chlamydomonas* and *volvox* move through water. Also the zoospores and motile gametes of lower plants show locomotion. These move in response to stimuli i.e sweet fluids etc. The protoplasm of the living cells of many plants shows streaming movements around vacuole.

Following are the types of the autonomic movements.

i. Epinasty ii. Hyponasty iii. Nutation

I. Epinasty

It is seen in the petals and leaves especially in the bud condition. The upper surface of the leaf shows more growth in the bud condition than the lower surface, which results in the opening of the buds.

ii. Hyponasty

It is also shown by petals and leaves in bud condition, the lower surface of the leave shows more growth than the upper surface which keeps the bud closed.

iii. Nutation

The growing tip of the young stem moves in zig zag manner due to alternate change in growth on opposite side of the apex.

Fig: 10.23 Young stem of Japanese Knotweed growing along the ground rather than upright into canes often have a zig-zag appearance.

b. Paratonic Movements

These movements are induced by the external stimuli. Paratonic movements may be:

i. Tropic movements

ii. Nastic movement

iii. Tactic movements

i. Tropic Movements

These are induced movement of curvature shown by the plant organ (shoot or root), which are capable of turning in any direction. The direction of movements is determined by the direction of stimulus (light, water, gravity etc). Tropism or tropic movements are classified as under:

a. Geotropism

Geotropism occurs in radially symmetrical organs like root and stem. The orientation of stem and roots in response to the force of gravity is called geotropism. The roots grows towards the force of gravity and are said to be positively geotropic, the stem grows away from the force of gravity and is there fore called negatively geotropic.

b. Phototropism

The tropic movement of curvature induced in plants organs in response to the unilateral effect of light is called phototropism.

Young stems are positive phototropic, turn towards light. The curvature is due to the greater growth on the shaded side then on the side on which the light acts. Roots are usually indifferent to stimulus of light, their orientation being determined chiefly by the gravity.

c. Hydrotropism

This is the movement of the plant organs in response to the stimulus of moisture. The primary roots, secondary roots of higher plants, rhizoid of liverwort and hyphae of certain fungi exhibit growth movement in response to variation in the amount of moisture. Roots are sensitive to variations in the amount of moisture in the soil.

d. Thigmotropism

These movements of the plant organs is in response to the stimulus of touch, contact or friction e.g. the plants, which climb by means of tendrils, are sensitive to the stimulus of contact. The tendrils are found in a number of plants e.g. in *Passiflora*, *Lathyrus*, *Smilax* etc.

Thigomotropic responses are also met within the roots. If the tip of the young root comes in contact with a solid object such as small stone, the root bends away from it. This negative curvature helps the root to avoid obstacle in the soil. The stamens of certain plants are sensitive to touch and their dehiscence takes place only when the body of an insect rubs them.

Fig:10.24 Passiflora species have tendrils that allow them to crawl all over everything.

(e. Chemotropism

This is the movement of a part of the plant in response to a chemical stimulus. The plant organ may grow either towards the chemical stimulus or away from it e.g. the pollen tube grows towards the egg in the angiosperms due to the disintegration of the synergid cells, which produced chemicals. Similarly the tentacles of *Drosera* (or sundew) show positive chemotropism. The chemicals like the proteins, phosphates and the salts of ammonia cause the tentacles to bend. In the same way the hyphae of many fungi shows positive chemotropism towards sugar, peptones. The hyphea of the fungi show negative chemotropism towards acids and alkalis.

ii. Nastic Movements

The movements brought about by the stimuli which are non directional but diffuse are called nastic movements. It is the variation in the intensity of some intensity of some external factor rather than its direction, which acts as a stimulus.

The direction of the movement is here determined by the structure of the plant organs like the leaves and the petals of flowers, which can bend only in one direction. Nastic movements may be the result of growth changes or they may be the movements of variation.

Nastic movements may be:

a Photonasty
b. Thermonasty
c. Seismonasty

a. Photonasty

This nastic movement is induced by variation in the intensity of light. Many leaves, which keep their surfaces fully exposed during the daytime, drop at night. The dropping of the leaves is brought about by changes in the turgidity of parenchymatous cells of the pulvini i.e. Many flowers such as oxalis close up at night or when the light is diminished on a cloudy day and open during the daytime in sunshine.

b. Thermonasty

This is due to variation in the degree of temperature. Many flowers open when illuminated and close up when it is dark e.g. crocus, tulips etc.

c. Seismonasty

This nastic movement is induced by mechanical stimuli such as touch or friction etc e.g. when the leaf of *Mimosa pudica* is touched the leaflets close and the whole leaf drops. This shock movement of *Mimosa pudica* is called seismonastic movement. These movements are caused by the differential loss and support of turgor on the two sides of the pulvinus.

iii. Tactic Movements

These are the movements of the entire organism or of motile organs and are induced by the external stimuli, which influence their direction. The stimuli can be light, temperature or chemicals.

a. Phototactic

It is the locomotary movement of free swimming organisms or their organs in response to one-sided illumination e.g. *Chlamydomonas*, *Volvox* and the zoospores of *Ulothrix* and many other algae when illuminated by weak light move towards the light, thus showing positive phototaxis. When illumination is too intense, they move away from light, showing negative phototaxis. Similar movements are also exhibited by the chloroplast in the pallisade cells of the green leaves.

b, Thermotactic

This is the movement of free organism in response to the stimulus of temperature. When there is difference in temperature, the unicellular algae are seen to move toward the warmer side.

c. Chemotactic

This is the movement of free organism or their gametes in response to chemical stimuli. The spermatozoids of bryophytes and pteridophytes move towards the chemical substances like sugar and proteins secreted by the archegonia.

Fig: 10.25 The sperm cells of ferns are typically multiflagellate.

For Your Information

Photoperiodism corodinates seasonal activities such as growth, development, reproduction, migration, and dormancy that make a direct contribution to survivorship and reproductive success of the species. Depending on the length of the day, animals show behavioural and biological changes. Day length affects their fur colour, migration, hibernation and also sexual behaviour. For example, the singing frequency of the canary bird depends on the length of the day.

10.7.3 Photoperiodism

The relative lengths of the day and night to which the plants are exposed have remarkable effects on the behaviour of plants particularly on the development of flowers. The relative length of the day and night to which the plant is exposed is called photoperiod and the response of the plant to photoperiod is the photoperiodism. According to photoperiodism, plants are classified into three types which are short day plants, long day plants and day neutral plants.

1. Short day plants

Short day plants produce flowers in early spring when the day length is shorter than a critical value Examples of short day plants are tobacco, Dahlia, Soya bean and *Chrysanthemum* etc. For short day plants the critical value is maximum for flowering.

2. Long day plants

Long day plants produce flowers in summer when the day length is longer than a critical value. Examples of long day plants are *Hibiscus*, beet, spinach and potato etc. For long day plants the critical value is a minimum value for flowering.

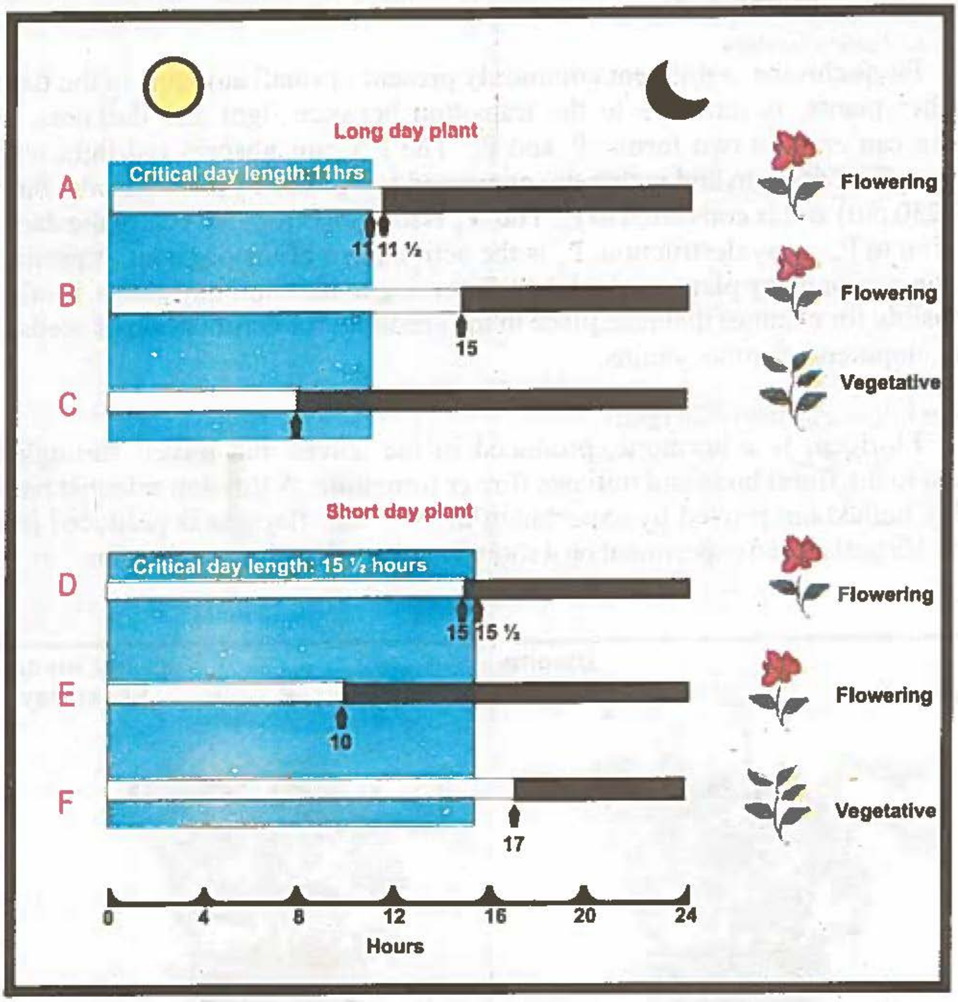


Fig: 10.26 Comparison of hypothetical long day and short day plants. The difference is that the critical day length is minimum value for the long day plant and maximum value short day plant. Thus the long dat plant will flower when the day length is slightly above the critical value (A) or when it is much above the critical value (B). But will not flower when it is below the critical value (C). Conversely, the short day plant will flower when the day length is slightly below the critical value (D) or when it is much below the critical value (E), but will not flower when it is above the critical value (F).

3. Day neutral plants

Day neutral plants are independent of the day length and therefore not affected by the day length. They produce flowers whenever they become mature, irrespective of the day length. Examples of day neutral plants are maize, tomato, sunflower and cucumber etc.

10.7.3.1 Phytochrome

Phytochrome, a pigment commonly present in small amounts in the tissues of higher plants, is sensitive to the transition between light and darkness. The pigment can exist in two forms, P_r and P_{fr} .The P_r forms absorbs red light with a wavelength of 660 nm and is thereby converted to P_{fr}. The P_{fr} form absorbs far red light (730 nm) and is converted to P_r. The P_{fr} is also lost from the cell in the dark by reversion to P_r, or by destruction. P_{fr} is the active form of the pigment. It promotes flowering in long day plants and inhibits flowering in the short day plants. P_{fr} also is responsible for changes that take place in the seedling, for germination of seeds and for development of anthocyanins.

Flowering hormone (Florigen)

Florigen, is a hormone, produced in the leaves and travels through the phloem to the floral buds and initiates flower formation. A Russian scientist named M. H. Chailakhain proved by experiment in 1936 that florigen is produced in the leaves. He performed experiment on a short day plant, the *Chrysanthemum.*

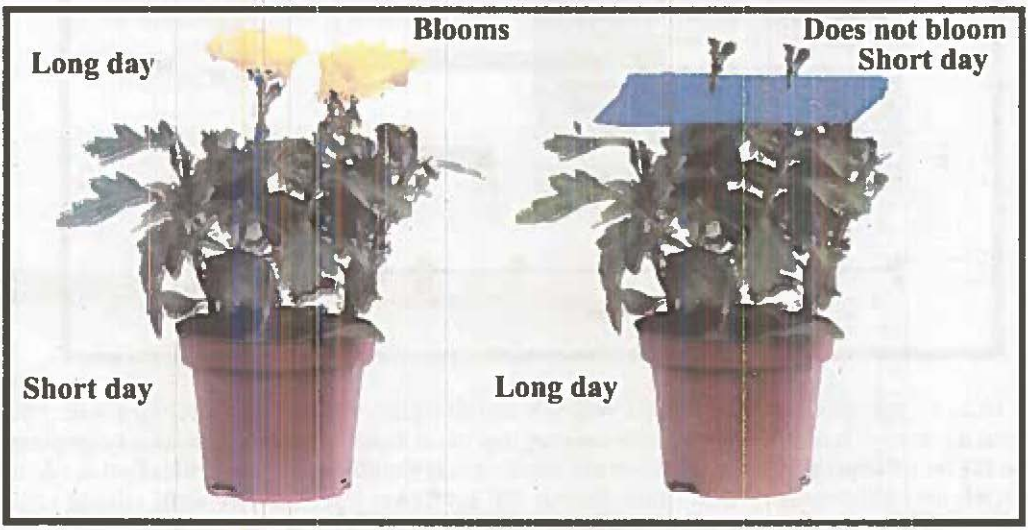


Fig: 10.27 Chailakhian experiment on short day plant *Chrysanthemum.*

He took two plants and removed the leaves from the upper half of both plants but left the leaves on the lower half. He then exposed the upper half of one plant to long days and the lower half of the same plant to short days. The result was that the plant produced flowers.

He then exposed the defoliated (leaves removed) upper half of the other plant to short days and the foliated lower half to long days. The result was that the plant produced no flowers. From this experiment Chailakhian, concluded that the flowering hormone or florigen is produced in the leaves and then transmitted to the floral bud where it initiates flower formation.

10.7.4 Vernalization

Vernalization is a Latin word meaning "spring". The conversion of winter variety into the spring variety by low temperature treatment is called vernalization. This term was coined by Lysenko in 1928. Some plants require a period of low temperature before producing flowers.

If this condition is not fulfilled, they will not produce flowers. For example, if the germinating seeds of winter wheat are exposed to low temperature, the plants developed from them will flower much earlier than would have done otherwise. This method of stimulating the earlier production of flowers by subjecting the germinating seeds to low temperature is known as vernalization. Vernalization is therefore the promotion of flowering by applying low temperature to seeds and buds before sowing or grafting. Vernalization is helpful to the agriculturists in inducing earlier development of flowers and earlier ripening of crops and also in extending cultivation to the regions where temperature is very low.

Fig: 10.28 Lysenko studying wheat

It has enabled the Russian farmers to grow crops in Siberia where the soil remains covered with ice for ten months of the year. Biennial and perennial plants are stimulated to flower by low temperature treatment. The embryo of the seed and apex of the stem are the parts which receive the stimulus of low temperature. Temperature around 4°C is found to be effective. It produces a hormone, the vernalin, which induce vernalization. Vernalization procedure was applied on large scale to cereal crops, particularly wheat in Northern Europe during 1930 and 1940, where the chilled winter varieties were grown as spring varieties.

KEY POINTS

- Depending upon the amount of each nutrient required the mineral nutrients are divided into two groups: macronutrients and micronutrients.
- Macro nutrients include nitrogen, phosphorus, potassium. calcium, magnesium, and sulfur. The micronutrients includes boron, copper, iron, chlorine.
- Carnivorous plants may be with passive traps or active traps in both of them method of insect decomposition involves digestive enzymes produced by the plant and bacterial decay within the trap.
- Tracheophytes' have specialised tissue, termed xylem and phloem, for conducting water (plus solutes) and organic nutrients.
- Water potential is directly proportional to the concentration of water-molecules. Greater the concentration of water molecules in a system, greater is the kinetic energy of water molecules.
- Water and minerals from the soil to the xylem moves by the way of appoplast, sympalst and through vacuoles.
- Four important forces combine to transport water solutions from the roots, through the xylem elements, and into the leaves. These TACT forces are: transpiration, adhesion, cohesion and tension.
- Green leaves are regarded as "source of assimilates " because these are the sites of production of sugar during the process of photosynthesis while the buds, seeds, fruits, roots and the underground stems are together called "sinks of assimilates" because sugar produced is either stored or utilized here.
- Osmoregulation has enabled the plants to be distributed in wide range of habitat.

KEY POINTS

- According to the amount of water available, plants are classified into four main groups: Hydrophytes, mesophytes, xerophytes and halophytes.
- Plants possess some morphological and anatomical structures to counter very high or very low temperature.
- Turgor pressure is caused by the uptake of water by the cytoplasm of the cells so that pressure is exerted at the plasma membrane on the cell wall.
- Growth is defined as increase in number and size of cells. Three phases of growth are: (a) Phase of cell division (b) Phase of cell elongation (c) Phase of cell maturation and differentiation.
- Apical meristems are areas of actively dividing cells at the tips of all roots and shoots. Lateral meristems consists of vascular cambium and cork cambium. Vascular cambium produces secondary vascular tissues and cork cambium produces cork cells, which protect the stem and root from water loss, pathogens, and herbivorous insects.
- The inhibition or control of lateral buds to develop by the activity of apical bud is called inhibitory correlation or apical dominance.
- Phytohormones are organic substances which are naturally produced in plants, control the growth or other physiological functions, at a sight remote from its place of production and active in extreme minute quantities.
- The relative length of the day and night to which the plant is exposed is called photoperiod and the response of the plant to photoperiod is the photoperiodism
- Phytochrome, a pigment commonly present in small amounts in the tissues of higher plants, is sensitive to the transition between light and darkness.
- The conversion of winter variety into the spring variety by low temperature treatment is called vernalization.

EXERCISE

A. Choose the correct answers in the following questions.

1. The thick walled dead cells like tracheid and vessels are included in:
   a. parenchyma b. sclerenchyma
   c. collenchyma d. mesenchyma

2 The increase in thickness of the plant due to the activity of cambium is called.
   a. primary growth b. secondary growth
   c. tertiary growth d. stunted growth

3 The movement restricted to bifacial organs like the leaves and petals of flower is the:
   a. tactic movement b. nastic movement
   c. tropic movement d. chemotactic movement

4 In plant, regions of continuous growth are made up of:
   a. dermal tissue b. vascular tissue
   c._meristematic tissue d. permanent tissue

5. Chlorosis is:
   a. the uptake of the micronutrient chloride by a plant.
   b. the formation of chlorophyll within the thylakoid membranes of a plant.
   c. yellowing leaves due to decreased chlorophyll production.
   d. a contamination of glassware in hydroponic culture.

6. Carnivorous plants have evolved mechanisms for trapping and digesting small animals. The products of this digestion are used to supplement the plant's supply of
   a. carbohydrates b. lipids and steroids
   c. nitrites d. water

7. All of the following are elements that plants need in very small amounts (micronutrients) **EXCEPT**
   a. Hydrogen b. Iron
   c. Chlorine d. Copper

8. The tissue most likely to provide flexible support is the:
   a. epidermis b. sclerenchyma
   c. parenchyma cell d. collenchyma

EXERCISE

9. Fibres like hemp and flax are made up of:
   a. epidermis
   b. sclerenchyma
   c. parenchyma cell
   d. collenchyma
10. The primary growth of a plant is due to the action of the ________.
    a. lateral meristem
    b. vascular cambium
    c. apical meristem
    d. cork cambium
11. Which bonds are responsible for the cohesion of water molecules?
    a. Ionic
    b. Hydrogen
    c. Non polar covalent
    d. Polar covalent
12. In a sugar sink, such as a taproot, sugar is converted into _____.
    a. fatty acid
    b. proteins
    c. glycogen
    d. starch
13. Plants are able to detect photoperiod changes by the _____.
    a. alternation of the two forms of phytochrome
    b. settling of amyloplasts
    c. direction of the light source
    d. movement of potassium ions
14. Which one of the following is true for annual ring?
    a. It is composed of a ring of early wood and a ring of late wood.
    b. Its growth is co-related with the production of abscisic acid.
    c. It is produced from the axillary buds.
    d. It is produced as a result of primary growth

B. Write short answers to the following questions.

1. Why insectivorous plants depend on insects?
2. What do you mean by water potential?
3. Differentiate between mesophytes and xerophytes.
4. How turgor provide support to the herbaceous plants?
5. Differentiate between primary and secondary growth in plants.
6. Briefly describe the mechanism of formation of annual rings in plants.
7. List the adaptation in plants to cope with low temperatures.

C. Answer the following questions in detail.

1. Elaborate the role of macro and micronutrients plant growth and development.
2. Explain the movement of water in xylem through TACT mechanism.
3. Explain the movement of sugars within plants.

EXERCISE

4. How the osmotic adjustments of plants in saline soils take place?.
5. Describe the structure of supporting tissues in plants.
6. Discuss the role of important plant growth hormones.
7. Classify plants on the basis of photoperiodism and give examples.
8. Describe the mechanism of opening and closing of stomata.

Projects:

- Prepare a temporary slide, by cutting a T.S of a dicot stem.
- Collect and write taxonomic classification of at least five plants exhibiting xerophytic, mesophytic and hydrophytic characters respectively.
- In your local area identify some major symptoms of mineral deficiencies in plants e.g. necrosis, chlorosis, stunted growth etc.

Chapter 11

Digestion

At the end of this chapter students will be able to:

- Describe the mechanical and chemical digestion in oral cavity.
- Explain swallowing and peristalsis.
- Describe the structure of stomach and relate each component with the mechanical and chemical digestion in stomach.
- Explain the role of nervous system and gastrin hormone on the secretion of gastric juice.
- Describe the major actions carried out on food in the three regions of the small intestine.
- Explain the absorption of digested products from the small intestine lumen to the blood capillaries and lacteals of the villi.
- Describe the component parts of large intestine with their respective roles.
- Correlate the involuntary reflex for egestion in infants and the voluntary control in adults.
- Explain the storage and metabolic role of liver.
- Describe composition of bile and relate the constituents with respective roles.
- Outline the structure of pancreas and explain its function as an exocrine gland.
- Relate the secretion of bile and pancreatic juice with the secretin hormone.
- Describe the causes, prevention, and treatment of the following disorders; ulcer, food poisoning, dyspepsia.
- Describe obesity in terms of its causes, preventions and related disorders.
- Explain the symptoms and treatments of bulimia nervosa and anorexia

Introduction

When we eat foods—such as bread, meat, and vegetables—they are not in a form that the body can use for nourishment. Food and drink must be changed into smaller molecules of nutrients before they can be absorbed into the blood and carried to cells throughout the body. Digestion is the process by which food is broken down into its smallest parts so the body can use them to build and nourish cells and to provide energy.

Digestion involves mixing food with digestive juices, moving it through the digestive tract, and breaking down large molecules of food into smaller molecules. Digestion begins in the mouth, when you chew and swallow, and is completed in the small intestine.

The digestive system is made up of the digestive tract—a series of hollow organs joined in a long, twisting tube from the mouth to the anus—and other organs that help the body break down and absorb food.There are also two solid digestive organs, the liver and the pancreas, which produce juices that reach the intestine through small tubes. In addition, parts of other organ systems (for instance, nerves and blood) play a major role in the digestive system.

11.1 Mechanical and Chemical Digestion in the Oral cavity

The **gastrointestinal tract** starts in the oral cavity where your teeth grind and chew food, breaking it into small manageable pieces. This chewing process, known as **mastication**, is dependent upon powerful muscles (masseter and temporalis), as well as smaller muscles that permit fine control; they move the mandible (lower jawbone) against the upper jaw and enable crushing of relatively hard food.

Mastication causes exocrine glands under the tongue and in the back of the mouth to secrete a watery liquid called **saliva** which performs two essential functions. It moistens and compacts the chewed food so your tongue can roll it into a ball (bolus) and push it to the back of your mouth for swallowing and easy passage through the pharynx and esophagus.

In addition, saliva contains **digestive enzymes** (e.g. salivary amylase) which begin the breakdown of carbohydrates. Mastication and saliva secretion work in harmony: chewing

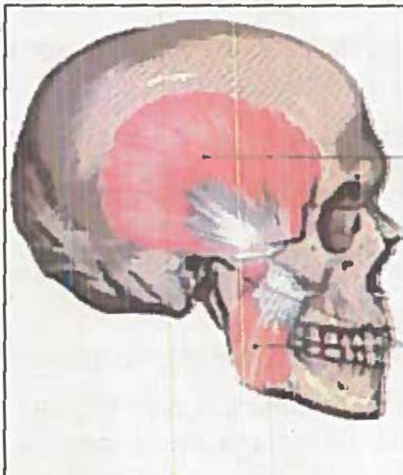


Fig: 11.1 Chewing process is dependent upon masseter and temporalis.

increases the surface area of foods which helps to accelerate the breakdown of starch molecules into simple sugars by the digestive enzymes. Almost no protein or fạt digestion occurs in the mouth, except for the release of **lingual lipase** an enzyme secreted by Ebner's glands on the dorsal surface of the tongue.

The actions of the teeth and tongue prepare food for swallowing. When you are ready to swallow, the tongue pushes a piece of chewed food (a bolus) toward the back of your throat and into the opening of the esophagus - the tube which leads to the stomach. To prevent food in the throat from rising into the nasal cavity or moving down the **windpipe** (trachea), the act of swallowing triggers two involuntary events. The **soft palate** (the back of the roof of the mouth) closes off the nasal cavity while the **epiglottis**, a flap of cartilage attached to the root of the tongue tilts downward to seal the **trachea**. The swallowing procedure is regulated by nerves in the medulla oblongata and pons. The reflex is instigated by receptors in the throat as a bolus of food is pushed to the back of the mouth by the tongue.

Note

Choking is a reflex action when food or liquid passes into the trachea; it involves a sudden forceful expulsion of air through the larynx to clear the airway.

11.1.1 Swallowing process

The three stages of swallowing are as follows:

Stage 1: The Oral Stage

Food is placed in the mouth. The process of chewing together with the stimulation of the gums and palate by the movement of food begins some of the reflex activities which take over once the food moves into Stage 2, the pharynx. Enzymes in the saliva help to form the food into a bolus, which the tongue squeezes into the pharynx by moving up towards the palate.

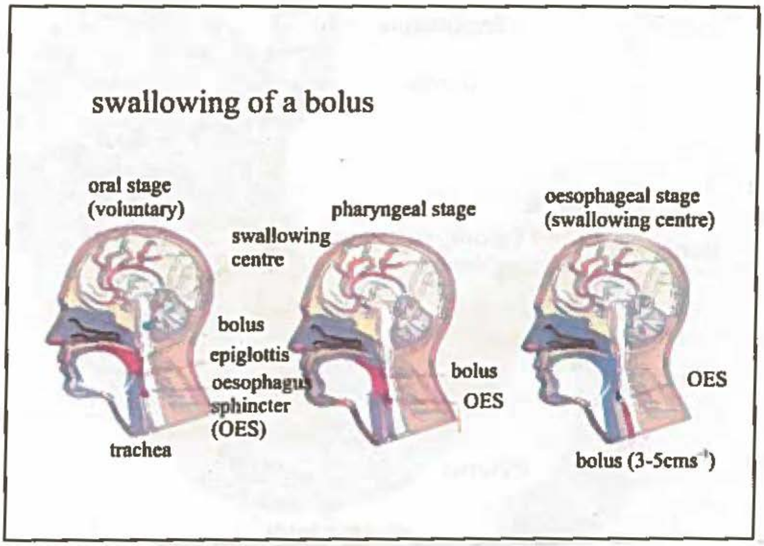


Fig: 11.2 Stages of swallowing process.

Stage 2: The Pharyngeal Stage

The larynx lifts up to meet the epiglottis, which lowers, making a seal that prevents material from entering the windpipe. This is important as it stops food or liquid from being aspirated into the lungs.

Stage 3: The Oesophageal Stage

The bolus is passed into the oesophagus by automatic contractions of the pharynx. It then travels to the stomach by gravity and reflex action. This stage of swallowing is entirely automatic and cannot be controlled.

11.1.2 Peristalsis

Once the food ball enters the esophagus, it is pushed towards the cardiac sphincter by smooth muscle contractions called peristalsis. Food travels from the mouth to the stomach in about 4 to 8 seconds. Peristalsis occurs throughout the length of the digestive tract and is responsible for keeping things moving and the occasional strange sounds that arise. The digestive tract is surrounded by both circular and longitudinal smooth muscle that allows for rhythmic contractions or peristalsis.

11.1.3 Food in stomach

Food enters the stomach from the esophagus, through the lower esophageal sphincter. The stomach is the part where physical and chemical breakdown of food really begins. It operates like a food mixer, churning the food bolus to a pulp called chyme, and releasing numerous chemicals such as digestive hormones, enzymes and gastric juices which help to break down food molecules in the chyme into small

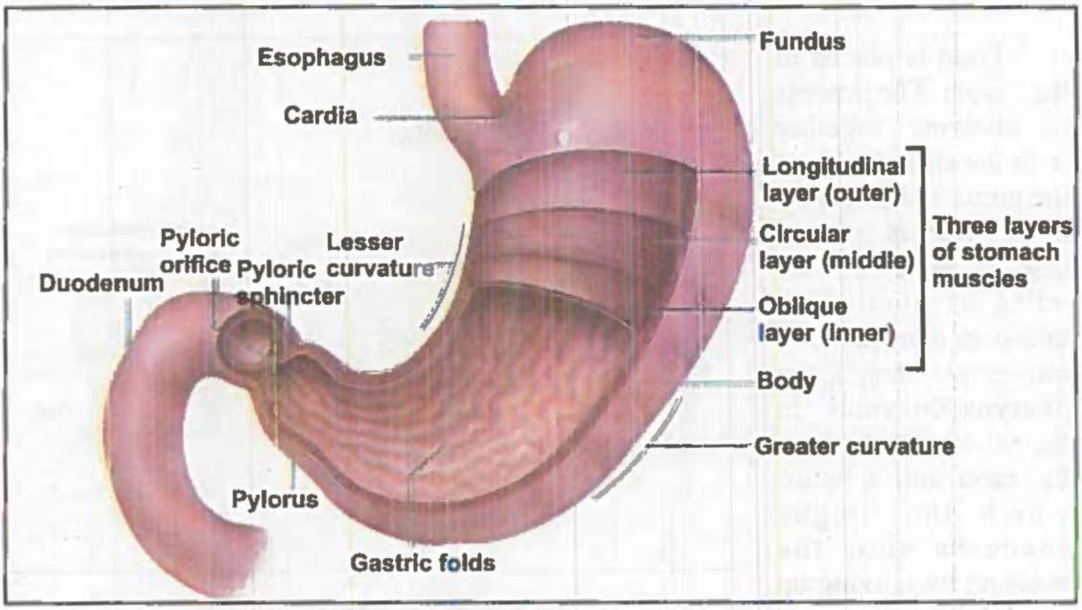


Fig: 11.3 Structure of stomach

particles for further digestion. An empty stomach has a volume of approximately 50 ml. But typically after a meal, its capacity expands to about 1 liter of food, and may expand to hold as much as 4 liters. The chyme slowly exits the stomach via the pyloric sphincter or valve and passes into the duodenum - the first segment of the small intestine - where digestion continues.

11.1.4 Structure of Stomach

The stomach is a muscular organ located on the left side of the upper abdomen. It is subdivided into 4 regions:

1. **Cardiac region**: Here the contents of the esophagus empty into the stomach through the lower esophageal or cardiac sphincter.
2. **Fundus:** An expanded area curving up above the esophageal opening.
3. **Body:** The central and largest region.
4. **Pylorus**: The narrow end of the stomach that joins the small intestine at the pyloric sphincter. Like the cardiac sphincter, the pyloric sphincter is a ring of muscle that regulates the movement of food out of the stomach.

The wall of the stomach is lined with millions of **gastric glands**, which together secrete 400–800 ml of gastric juice at each meal. Several kinds of cells are found in the gastric glands

- parietal cells
- chief cells
- mucus-secreting cells
- hormone-secreting (endocrine) cells

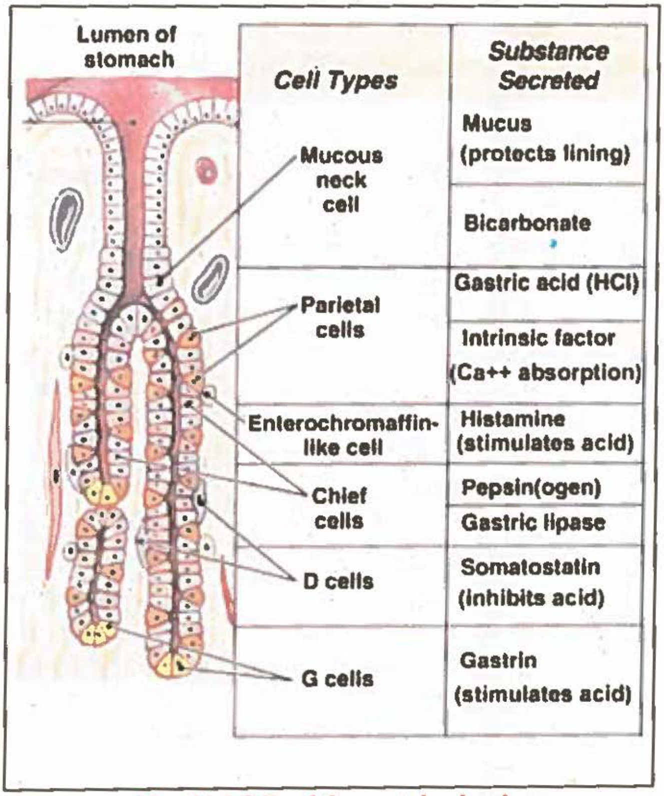


Fig: 11.4 Cells of the gastric glands

a. Parietal cells

Parietal cells secrete

- hydrochloric acid
- intrinsic factor

I. Hydrochloric acid (Hcl)

Parietal cells contain a H^+ and ATPase. This transmembrane protein secretes H^+ ions (protons) by active transport, using the energy of ATP. The concentration of H^+ in the gastric juice can be as high as 0.15 M, giving gastric juice a pH some what less than 1.

ii. Intrinsic factor

Intrinsic factor is a protein that binds ingested vitamin B_{12} and enables it to be absorbed by the intestine in intact form.

b. Chief cells

The chief cells synthesize and secrete pepsinogen, the precursor to the proteolytic enzyme pepsin.

c. Mucus secreting cells

Special cells secrete a protective coating called mucus, on the stomach walls to prevent damage from gastric acids. Originally it was thought that peptic ulcers were caused by an erosion of this mucus lining by these acids. However recent research indicates that these ulcers are caused largely by the spread of a type of bacteria called *Helicobacter pylori* bacterium into the gastric walls.

d. Hormone secreting cells

Secretion by the gastric glands is stimulated by the hormone gastrin. Gastrin is released by endocrine cells in the stomach in response to the arrival of food.

11.1.5 Absorption in the stomach

Very little absorption occurs in stomach. However, some water, certain ions, and drugs like aspirin and ethanol are absorbed from the stomach into the blood (accounting for the quick relief of a headache after swallowing aspirin).

11.1.6 Functions of the Stomach

Although it is a very complex organ which performs a wide variety of digestive actions, the stomach has three main functions:

- It stores the food. This allows us to eat a large number of food calories in a relatively short time and then digest it over a longer period. Without the stomach's storage capacity, we would need to eat very small amounts of food continuously throughout the day, because the small intestine digests food very slowly.
- It breaks down large fat and protein molecules in food, so they can be absorbed in the small intestine. To do this, the stomach releases a number of powerful **gastric juices** containing hydrochloric acid and other digestive enzymes. In addition to breaking down food, these acidic juices (pH 1-3) also kill bacteria in the food. For easier digestion, powerful muscles in the stomach wall churn the food into a paste of porridge-like consistency, called chyme. This churning action also ensures that the secreted gastric acids and enzymes are thoroughly mixed with the food.

- **It empties the partially digested chyme into the duodenum** (the first segment of the small intestine) at a manageable speed, through the the pyloric sphincter. While the intestine is full and still digesting food, the stomach acts as storage area for food. The absorption of food and water by the stomach is negligible, but iron and highly fat-soluble substances like alcohol are absorbed directly.

11.1.7 Mechanism of secretion of gastric juice

An interesting question is raised here. What causes gastric juice to be secreted? There are two possible answers to this question – chemical control and nervous control. Sometimes even the sight, smell, taste or hearing of delicious food, stimulate the nervous system which orders for the secretion of small amount of gastric juice like watering of mouth. This is proved by the experiment of Russian, Pavlov. He cut the esophagus of a dog and left the cut end open to the outside.

When he fed this dog, the food, of course, never reached the stomach, yet the stomach resulted in the secretion of about one fourth the normal amount of gastric juice. This showed that the gastric secretion was under the reflex control and cutting of the gastric nerves proved it. If there are more proteins in the food, a signal is sent to the brain which in response to this signal order the gastric glands to secrete more gastric juice.

A hormone called gastrin, controls the secretion of gastric juice. Protein molecules stimulate the endocrine cells of the stomach to secrete gastrin. The liberating gastrin is soon absorbed by the blood which carries it to the gastric glands to secrete large amount of gastric juice in the stomach. The contact of the food with the lining of the stomach also causes the cells to secrete gastrin which stimulated the gastric glands to secrete gastric juice.

11.2 Food in the Small Intestine

As the contents of the stomach become thoroughly liquified, they pass into the **duodenum**, the first segment (about 10 inches long) of the small intestine. Food typically takes 4-5 hours to pass through the stomach into the duodenum, the first part of the small intestine.After being churned and mixed with digestive juices in the stomach, food chyme moves slowly into the folds of the small intestine through the pyloric sphincter or valve. The small intestine (or small bowel) is the longest section of the digestive tract (approx 17 feet) and is divided into three segments: the duodenum, jejunum and ileum, each of which performs different digestive functions. Chyme from the stomach is propelled through the small intestine by peristalsis.

11.2.1 Functions of the Small Intestine

The small intestine is where most chemical digestion takes place; peptides (complex chains of protein molecules) are broken down into amino acids; lipids (fats) are broken down into fatty acids and glycerol; and carbohydrates are broken down into

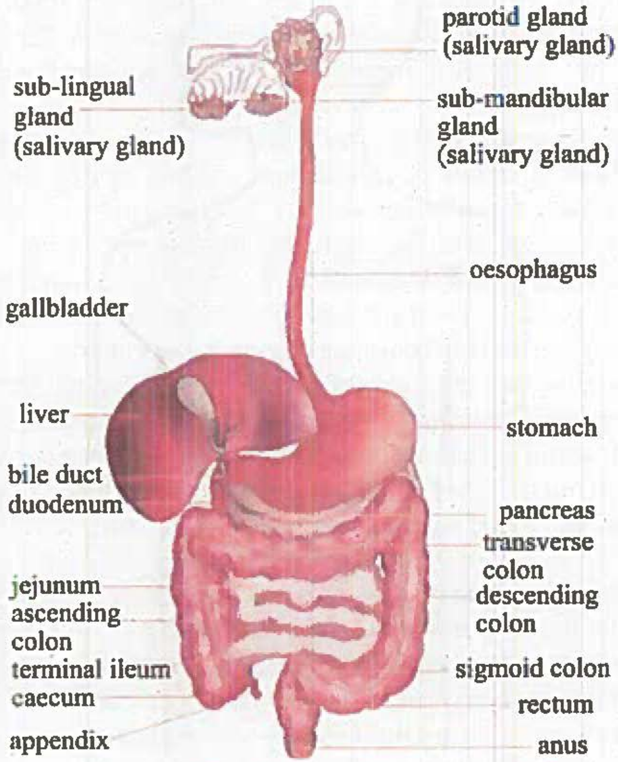


Fig: 11. 5 The Human Alimentary canal

simple sugars like glucose. To accomplish this, chyme is mixed with additional digestive juices including bile from the liver and pancreatic juice and amylase from the pancreas, as well as other intestinal enzymes such as maltase, lactase and sucrase to break down the chyme and assist in nutrient absorption. Absorbed nutrients flow in the bloodstream to the liver where they are further metabolized and then either stored or sent to cells in other parts of the body. In total, food typically takes 4-5 hours to transit all three sections of the small intestine. Along the way its consistency changes from porridge (chyme) to a thin watery mixture.

Do You Know?

Since the small intestine (about 17 feet) is much longer than the large intestine (about 5 feet) people often wonder why it is referred to as "small". The answer lies in its diameter (3-4 cm), which is about 3 times narrower than the "large" intestine.

11.2.2 Digestive Function of the Duodenum

The duodenum continues the process of food breakdown. Its name stems from the Latin "duodenum digitorum", meaning twelve fingers or inches. It is roughly horse-shoe-shaped. Anatomically, it is is sub-divided into four segments: the superior, descending, horizontal and ascending duodenum. Inside the duodenal tube, chyme is mixed with fluids from the gallbladder (bile) and pancreas (pancreatic juice). Bile breaks down fat particles into smaller droplets, while pancreatic juice contains enzymes that convert fats into fatty acids and glycerol, and sodium bicarbonate to neutralize stomach acid.

11.2.3 Digestive Function of the Jejunum

Roughly 4-7 feet in length, the jejunum is where chemical breakdown of the food chyme is completed. Pancreatic enzymes, along with enzymes produced by the jejunum wall, finalize the food digestion process. The term jejunum stems from the Latin jejunus, meaning empty.

11.2.4 Digestive Function of the Ileum

Ileum is 5-7 feet long. It is the final section of the intestine and is connected to large intestine by the ileocecal valve.The main function of the ileum is to absorb nutrients. Bile is also absorbed here and returns to the liver through blood vessels in the intestinal walls.The unabsorbed watery remains of the food chyme now pass into the large intestine for water-removal and final processing, before being expelled from the body.

11.2.5 Absorption of Nutrients in the Small Intestine

It is inside the small intestine that we absorb most of the nutrients in our food. Although the small intestine has a relatively small diameter, the intestinal walls are covered in wrinkles called rugae, which are themselves covered in millions of finger-like projections called villi, which are themselves studded with millions of smaller projections called microvilli. This provides a surface-area of about the size of a tennis court for nutrient absorption. Inside each villus is a series of lymph vessels (lacteals) and blood vessels (capillaries). The lacteal lymph vessel absorbs digested fat into the lymphatic system which eventually drains into the bloodstream. The blood vessels receive other nutrients and transport them via the hepatic portal vein to the liver. Here the blood is filtered, toxins are removed and the nutrients are processed. An important task performed by the liver in this context is the regulation of blood glucose levels to provide sufficient energy for the body. Excess glucose is converted in the liver to glycogen in response to the hormone insulin, and stored. When blood glucose levels begin to drop, (eg. between meals), the glycogen is re-converted to glucose in response to messages conveyed by the hormone glucagon.

11.3 Digestion in the Large Intestine

After all nutrients have been absorbed from ingested food during its passage through the small intestine, the watery waste passes into the large intestine. It is the final section of the gastrointestinal tract and its main function is to remove water (plus any remaining minerals) from the food waste and compress it into a form for easy expulsion from the body. As the chyme passes through the large intestine, the water is removed and the chyme is combined with mucus and bacteria (gut flora), and is converted into feces.

As in the esophagus and small intestine, undigested food is propelled through the large intestine by waves of muscular contraction and expansion, called peristalsis. However, unlike in the small intestine where these waves occur at irregular intervals, peristalsis in the large intestine is continuous. In addition, 2-3 times a day, a more vigorous type of movement (gastrocolic reflex) occurs which propels material towards the rectum and anus. As waste matter is pushed into the rectum, it triggers a desire to defecate.

11.3.1 Structure of the large intestine

The large intestine (also referred to as the large bowel, or the lower gastrointestinal tract) is a thick tube of about 5 feet in length which gets progressively narrower in diameter. It consists of four regions: the ceacum, colon, rectum, and anal canal. (The term "colon" is sometimes used to describe the entire large intestine). The cecum (or caecum) is a short pouch into which food enters from the ileum (via the ileocecal valve) and exits into the ascending colon of the large intestine. The colon is the longest segment of the large intestine. It is sub-divided into four sections, named after their position in the pelvis: the ascending colon, transverse colon, descending colon and sigmoid colon. The rectum is the final part of the large intestine. Feces formed in the colon collect in the rectum before being excreted via the anus. After the rectum comes the anal canal, a short passage about 1.5 inches long, terminating in two muscular rings: the internal and external sphincters. As waste products from the rectum pass into the anal canal, nerves in the rectum cause the internal sphincter to relax and open. Then the external sphincter also relaxes, permitting fecal discharge.
Defecation may be involuntary or under voluntary control. Young children learn voluntary control through the process of toilet training. Once trained, loss of control causing fecal inconvenience may be caused by physical injury (such as damage to the anal sphincter, intense fright, inflammatory bowel disease, impaired water absorption in the colon and psychological or neurological factors.

11.4 Liver

The liver is one of the most important and largest organ in the human body. It is located in a central position of the abdomen, and is closely involved in almost every aspect of the body's physiological activities. Because of its central role, liver disease

can be extremely life-threatening. The liver has a multitude of important and complex functions. Some of these functions are:

a. Carbohydrate metabolism

Glucose is a vital energy source for cells and its levels in the blood stream must remain constant. The liver helps maintain blood glucose levels in response to the pancreatic hormones insulin and glucagon. After a meal, glucose enters the liver and levels of blood glucose rise. This excess glucose is dealt with by **glycogenesis** in which the liver converts glucose into glycogen for storage. The glucose that is not stored is used to produce energy by a process called glycolysis. This occurs in every cell in the body.

In between meals or during starvation, blood glucose levels fall. The hepatocytes (bile secreting liver cells) detect this change, and restore glucose levels by either glycogenolysis which converts glycogen back to glucose, or gluconeogenesis in which non-sugars such as amino-acids are converted to glucose.

b. Fat metabolism

The liver is involved in fat metabolism and synthesizes lipoproteins, cholesterol and phospholipids essential for many body functions. If fat is in excess, the liver prepares for storage. Lipogenesis is the metabolic process in which fats, composed of fatty acids and glycerol, are converted for storage in subcutaneous tissue and other storage depots.

If energy and glucose levels are low, stored fat is converted back into glycerol and fatty acids by a process called lipolysis. This occur in adipose cells, but the fatty acids and glycerol are transported to the liver for use as an alternative energy supply.

c. Protein metabolism

Amino acids are transported to the liver during digestion and most of the body's protein is synthesized here. If protein is in excess, amino acids can be converted into fat and stored in fat depots, or if required, made into glucose for energy by gluconeogenesis which has already been mentioned. However, before amino acids can be utilized in these ways, the first step is to remove the nitrogen-containing amino group NH_2. This very important metabolic process is called deamination.In the hepatocytes, NH_2 (the amino group) quickly changes into ammonia NH_3, which is highly toxic to the body. The liver acts fast to convert ammonia into urea that then can be excreted in the urine and eliminated from the body.

d. Detoxification

The liver plays a vital role in detoxification and destruction of endogenous and exogenous harmful substances. The liver's own phagocytes which reside within the lobules, known as Kupffer cells, digest and destroy cellular debris and any invading bacteria. Other exogenous substances such as drugs and alcohol are detoxified by the liver. Amino acids are deaminated, some hormones are inactivated, and bilirubin, a product of the breakdown of old red blood cells, is also detoxified and rendered

harmless by liver metabolism.

e. Storage

The liver plays an important role as a storage facility. The hepatocytes take up many types of vitamins and minerals from the blood and store them. These include vitamins A, B_{12}, D, E, K and minerals like iron and copper. Glycogen which is formed from excess glucose is also stored by the liver, although muscle tissue can also store glycogen too.

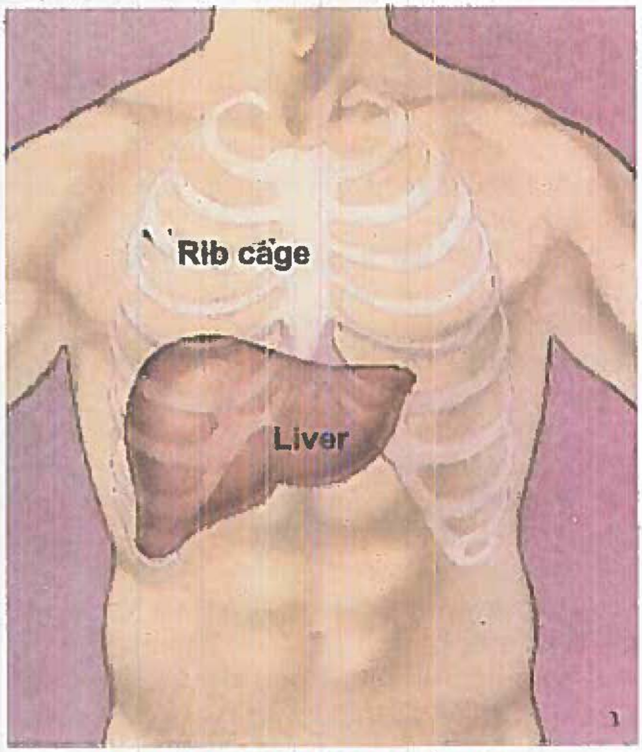


Fig: 11. 6 Location of Liver in rib cage

f. Bile

The liver synthesizes bile which is important for fat digestion and is also a route of excretion from the body. Bile consists of water, bile salts, cholesterol, phospholipids, electrolytes and bile pigments which give it its typical yellowish-green colour. Bile is stored and concentrated in the gall bladder. The presence of fats in the gut during meals stimulates the gall bladder to empty. Bile enters the duodenum emulsifying fats into smaller globules, which can then be broken down further by lipase enzymes. Metabolic wastes and drug products may form part of the bile which can then be excreted from the body through the digestive tract in the faeces. Bilirubin, the toxic end product of haemoglobin breakdown, is excreted from the body in this way.

11.5 Pancreas

The pancreas is located in the abdomen. It is pink in color and lies in close to the duodenum. It can be divided into three regions: the head, the body and the tail. The head is an expanded portion that lies in the C-shaped region of the duodenum to 'which it is intimately attached by connective tissue, and which is connected by a common blood supply. The body and tail extend across the midline of the body towards the hilum of the spleen.

11.5.1 Structure of Pancreas

The bulk of the pancreas is composed of pancreatic exocrine cells and their associated ducts. Embedded within this exocrine tissue are roughly one million small clusters of cells called the ***Islets of Langerhans***, which are the endocrine cells of the pancreas and secrete insulin, glucagon and several other hormones.

Pancrease has two main components – Acinar cells and Ducts. These two constitute 80% to 90% of the pancreatic mass. Twenty to forty acinar cells join into a unit called the acinus. Acinar cells secrete the digestive enzymes. In each acinus another type of cells called centroacinar cells are present which are responsible for fluid and electrolyte secretion by the pancreas.

Ductular system of pancreas consists of a network of conduits that carry the exocrine secretions into the duodenum. The contents of acinus drains into small intercalated ducts and then to interlobular duct from where it passes into pancreatic duct. Interlobular ducts contribute to fluid and electrolyte secretion along with the centroacinar cells

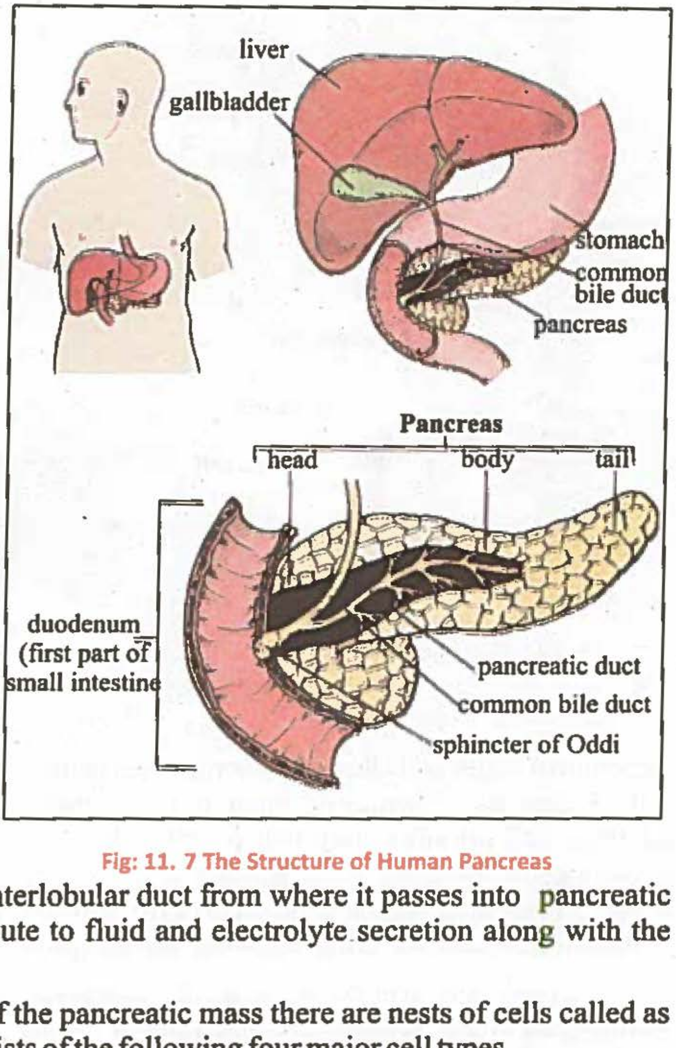


Fig: 11. 7 The Structure of Human Pancreas

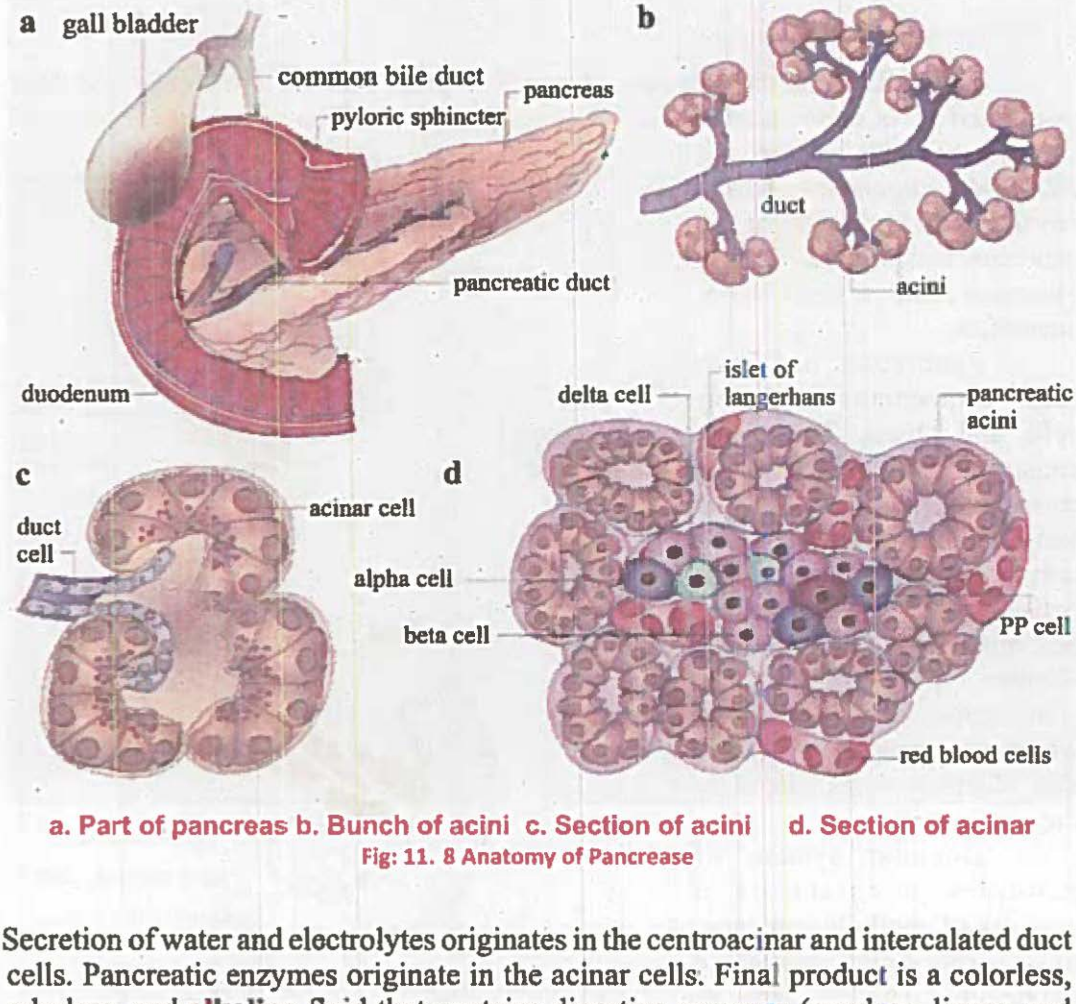
Accounts for only 2% of the pancreatic mass there are nests of cells called as islets of Langerhans which consists of the following four major cell types

a. Alpha (A) cells secrete glucagon.

b. Beta (B) cells secrete insulin.

c. Delta (D) cells secrete somatostatin.

d. F cells secrete pancreatic polypeptide.



a. Part of pancreas b. Bunch of acini c. Section of acini d. Section of acinar

Fig: 11. 8 Anatomy of Pancrease

Secretion of water and electrolytes originates in the centroacinar and intercalated duct cells. Pancreatic enzymes originate in the acinar cells. Final product is a colorless, odorless, and **alkaline** fluid that contains digestive enzymes (amylase, lipase, and trypsinogen). 500 to 800 ml of pancreatic fluid is secreted per day. Alkaline pH results from secreted bicarbonate which serves to neutralize gastric acid and regulate the pH of the intestine. Enzymes digest carbohydrates, proteins, and fats.

Acinar cells secrete isozymes like amylases, lipases, and proteases. These are synthesized in the endoplasmic reticulum of the acinar cells and are packaged in the zymogen granules. Released from the acinar cells into the lumen of the acinus and then transported into the duodenal lumen, where the enzymes are activated

Amylase is the only digestive enzyme secreted by the pancreas in an active form. It functions optimally at a pH of 7. It hydrolyzes starch and glycogen to glucose, maltose, maltotriose, and dextrins. Lipase function optimally at a pH of 7 to 9. It emulsify and hydrolyze fat in the presence of bile salts. Proteases are essential for

protein digestion. These are secreted as proenzymes and require activation for proteolytic activity. Duodenal enzyme, enterokinase, converts trypsinogen to trypsin. Trypsin, in turn, activates chymotrypsin, elastase, carboxypeptidase, and phospholipase.

11.6 Relation of bile and pancreatic juice with the secretin hormone

The small intestine periodically receives acid from the stomach, and it is important to put out that fire in a hurry to avoid acid burns. Secretin functions as a type of fireman: it is released in response to acid in the small intestine, and stimulates the pancreas and bile ducts to release a flood of bicarbonate base, which neutralizes the acid. Secretin is also of some historical interest, as it was the first hormone to be discovered.

Secretin is secreted in response to one known stimulus: acidification of the duodenum, which occurs most commonly when liquified ingesta from the stomach are released into the small intestine.

The principal target for secretin is the pancreas, which responds by secreting a bicarbonate-rich fluid, which flows into the first part of the intestine through the pancreatic duct. Bicarbonate ion is a base and serves to neutralize the acid, thus preventing acid burns and establishing a pH conducive to the action of other digestive enzymes. A similar, but quantitatively less important response to secretin is elicited by bile duct cells, resulting in additional bicarbonate being dumped into the small gut. As acid is neutralized by bicarbonate, the intestinal pH rises toward neutrality, and secretion of secretin is turned off.

11.7 Disorders related to digestive system and food habits

Following are some of the disorders related to digestive system and general food habits.

11.7.1 Ulcer

Destruction of the gastric or intestinal mucosal lining of the stomach by hydrochloric acid is a direct cause of peptic ulcer. Infection with the bacterium *Helicobacter pylori* is thought to play an important role in causing both gastric and duodenal ulcers. *Helicobacter pylori* may be transmitted from person to person through contaminated food and water.

Injury of the gastric mucosal lining, and weakening of the mucous defenses are also responsible for gastric ulcers. Excess secretion of hydrochloric acid, genetic predisposition, and psychological stress are important contributing factors in the formation and worsening of duodenal ulcers. Another major cause of ulcers is the chronic use of anti-inflammatory medications, such as aspirin. Cigarette smoking is also an important cause of ulcer formation and ulcer treatment failure.

The stomach defends itself from hydrochloric acid and pepsin by creating a mucus coating (that shields stomach tissue), by producing bicarbonate and by circulating blood to the stomach lining to aid in cell renewal and repair. If any of these functions are impaired it can lead to the formation of an ulcer. Peptic ulcers were formerly thought to be caused by stress, coffee consumption, or spicy foods. Now it is clear that about 60% of peptic ulcers are caused by a bacterial infection that can usually be cured. The bacterium (*H. pylori*) was established as the leading cause of peptic ulcers in the early 1980s. It was also found to cause gastritis (inflammation of the stomach lining).

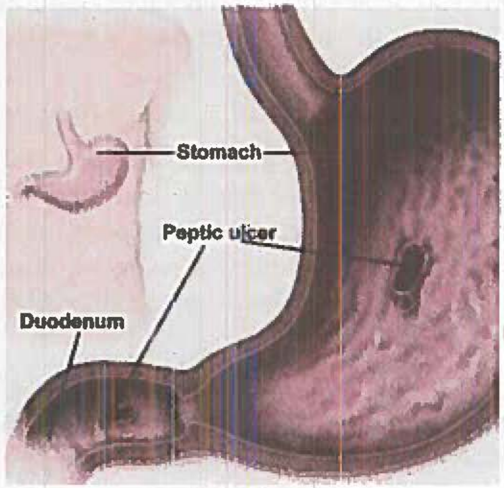


Fig: 11.9 Ulcer is the destruction of mucosal lining.

H. pylori weakens the stomach's defenses by thinning the mucous coating of the stomach, making it more susceptible to the damaging effects of acid and pepsin; inflaming the area; poisoning nearby cells and producing more stomach acid.

Treatment

Most commonly, ulcers related to *H. pylori* are treated with a two week course of treatment called triple therapy, consisting of two antibiotics to kill the bacteria and either an acid suppressor or stomach-lining shield medication.

11.7.2 Obesity

Obesity refers to an increase in total body fat. Obesity or weight gain occurs when we eat more calories than our body uses up. If the food we eat provides more calories than our body needs, the excess is converted to fat. Initially, fat cells increase in size. When they can no longer expand, they increase in number. If we lose weight, the size of the fat cells decreases, but the number of cells does not.

a. Causes of obesity: Obesity, however, has many causes. The reasons for the imbalance between calorie intake and consumption vary by individual. Age, sex, and genes, psychological makeup, and environmental factors all may contribute.

b. Genes and environmental factors: Having obese relatives does not guarantee that you will be obese; however, obesity tends to run in families. This is caused both by genes and by shared diet. The most important environmental factor is lifestyle. Your eating habits and activity level are partly learned from the people around you.

Overeating and sedentary habits (inactivity) are the most factors for obesity.

c. Age and Sex: People tend to lose muscle and gain fat as they grow older. Their metabolism also slows somewhat. Both of these lower their calorie requirements. Men have more muscle than women, on average. Because muscle burns more calories than other types of tissue, men use more calories than women, even at rest. Thus, women are more likely than men to gain weight with the same calorie intake.

d. Emotions: Some people overeat because of depression, hopelessness, anger, boredom, and many other reasons that have nothing to do with hunger. Their feelings influence their eating habits, causing them to overeat.

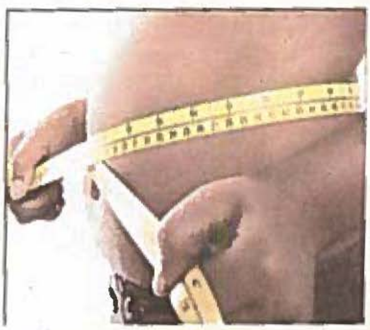
e. Pregnancy: Women tend to weigh an average of 4-6 pounds more after a pregnancy than they did before the pregnancy. This weight gain may contribute to obesity in women.

f. Medical conditions and Medications: Certain medical conditions and medications can cause or promote obesity, although these are much less common causes of obesity than overeating and inactivity. Some examples of these are as follows: Hypothyroidism, Cushing syndrome, Depression.

g. Risk factors associated with obesity

It is the second leading cause of preventable death (after smoking), and is associated with type II diabetes, hyperlipidaemia (presence of excess lipids in the blood), coronary artery disease, arthritis, gallstones, psychosocial disability. Certain cancers - colon, rectum and prostate in men; uterus, biliary tract, breast and ovary in women - are more prevalent in the obese.

Are you obese or not? Try this.



The easiest and most widely accepted method of determining whether you are obese is by measuring your Body Mass Index, or BMI. To calculate your BMI, follow these steps:

1. Multiply your weight in pounds by 705; divide by your height in inches; divide this number by your height in inches a second time.

A normal BMI = 18.5 to24.9; overweight=25.0 to 29.9; obese = 30 or greater; and morbidly obese = 40 or greater.

h. Treatment of Obesity

Successful programs for weight loss reduction and maintenance should be started and followed under the care of a physician and/or a nutritionist. A weight-loss program may include:

- Exercise (30 minutes of physical activity on most days of the week)
- A low-fat, high-complex carbohydrate, high fiber diet
- Behavior modification to change eating behavior
- Social support
- Medications

11.7.3 Bulimia nervosa

Bulimia nervosa is an eating disorder in which a person may eat a lot of food at once and then try to get rid of the food by vomiting, using laxatives, or sometimes over-exercising. People with bulimia are preoccupied with their weight and body image. Bulimia is associated with depression and other psychiatric disorders and shares symptoms with anorexia nervosa, another major eating disorder. Because many individuals with bulimia can maintain a normal weight, they are able to keep their condition a secret for years. If not treated, bulimia can lead to nutritional deficiencies and even fatal complications.

a. Signs and Symptoms:

Bulimia is often accompanied by the following signs and symptoms:

- Binge eating of high-carbohydrate foods, usually in secret
- Exercising for hours
- Eating until painfully full
- Going to the bathroom during meals
- Body weight that goes up and down
- Constipation, diarrhea, nausea, abdominal pain
- Dehydration
- Irregular menstruation or lack of menstrual periods in females
- Damaged tooth enamel, bad breath, sore throat or mouth sores
- Depression

b. Treatment:

Psychotherapy is a cornerstone of bulimia treatment. Cognitive behavioral therapy, which teaches you to replace negative thoughts and behaviors with healthy ones, is often used. Other mind-body and stress-reduction techniques, such as yoga, tai chi, and meditation, may help you become more aware of your body and form a more positive body image.. It is important for the person with bulimia to be actively involved in their treatment. Antidepressants are often prescribed for bulimia.

11.7.4 Anorexia nervosa

Anorexia is an emotional disorder that focuses on food, but it is actually an attempt to deal with perfectionism and a desire to control things by strictly regulating food and weight. People with anorexia have an extreme fear of gaining weight, which causes them to try to maintain a weight far less than normal. They will do almost anything to avoid gaining weight, including starving themselves or exercising too much. Anorexia most commonly affects teens. Although anorexia seldom appears before puberty.It can be a chronic disease, one that you deal with over your lifetime. But treatment can help you develop a healthier lifestyle and avoid anorexia's complications.

a. Signs and Symptoms:

The primary sign of anorexia nervosa is severe weight loss. People with anorexia may try to lose weight by severely limiting how much food they eat. They may also exercise excessively. Some people may engage in binging and purging, similar to bulimia. They may vomit after eating or take laxatives. At the same time, the person may insist that they are overweight.

b. Physical Signs

- Excessive weight loss
- Very rare menstrual periods
- Thinning hair, dry skin
- Bloated or upset stomach
- Low blood pressure
- Fatigue
- Abnormal heart rhythms
- Osteoporosis

c. Psychological and Behavioral Signs

Anorexia patients have distorted perception of self (insisting they are overweight when they are thin). Being preoccupied with food thoughts they refuse to eat and also refusing to acknowledge the seriousness of the illness. They suffer from

depression and refuse to eat in public. Such patients constantly weigh themselves and do regular excercises.

e. Treatment:

The most successful treatment is a combination of psychotherapy, family therapy, and medication. It is important for the person with anorexia to be actively involved in their treatment.

11.7.5 Food Poisoning

This type of intestinal condition is characterized by sudden illness caused by eating food or drinking liquids contaminated by a toxin or infectious organism. Poor food hygiene is a risk factor.

a. Symptoms of food poisoning

The symptoms may start hours or days after consuming the contaminated food. Usually the symptoms are confined to the gastrointestinal tract. However, some food poisoning may cause more widespread symptoms. For example, the *Clostridium Botulinum* bacterium (Botulism) causes muscle weakness and paralysis, and Listeriosis may cause flu-like symptoms and lead to meningitis.

b. Causes of food poisoning

Most cases of food poisoning result from contamination of food or water by bacteria, viruses or, less commonly, protozoan parasites. Unhealthy food hygiene can enable these microorganisms to multiply. In some cases of bacterial food poisoning, it is not the presence of the bacteria themselves that cause poisoning but the effect of toxins produced by the bacteria. If infectious organisms are ingested with the food they can multiply in the digestive tract. If the food poisoning is caused by bacterial toxins, they may be produced in the food before it is eaten. Most types of food poisoning cause diarrhea and/or vomiting, often with abdominal pain. The severity of symptoms and the speed at which they develop and the duration of the illness depends on the cause of food poisoning.

Major food Poisoning Agents

- I. ***Staphylococci***
- ii. ***Escherichia Coli***
- iii. ***Salmonella***
- iv. ***Campylobacter***

c. Treatment of food poisoning

Treatment of food poisoning is usually aimed at preventing dehydration. In severe cases fluids and salts may be administered intravenously in hospital. Typically,

antibotics are prescribed only if specific bacteria have been identified. Patients usually recover quite rapidly from an attack of food poisoning and rarely experience longlasting health consequences. In very rare cases, there is a risk of **septicemia** if bacteria spread into the blood stream. Both dehydration and septicemia can cause shock - a condition that is sometimes fatal.

11.7.6 Dyspepsia

Pain or discomfort in the upper abdomen that is not associated with a structural abnormality. Dyspepsia describes recurrent and persistent indigestion that occurs without an identifiable cause or abnormality of the digestive tract. The condition is more common in adults, especially men, and may be made worse by stress, obesity, smoking and a diet high in rich, fatty foods.

a. Symptoms of dyspepsia

The symptoms of dyspepsia may include pain in the upper abdomen, often made worse by eating, and nausea, particularly in the morning. Patients with Non-ulcer Dyspepsia often experience these symptoms several times a week for months.

b. Treatment for dyspepsia

A blood test may be carried out to check for infection of the stomach lining from the bacterium *Helicobacter pylori*. Also, upper digestive tract endoscopy or contrast X-Rays may be carried out to look for abnormalities in the gastrointestinal tract.

c. Prevention of dyspepsia

In order to help reduce both the frequency and severity of bouts of indigestion, follow these steps:

- Eat small portions of food at regular intervals, without eating too fast or overfilling your stomach.
- Avoid eating in the three hours before going to bed to allow your body enough time to digest food.
- Avoid rich, fatty foods such as butter and fried foods.
- Learn to overcome stress, which can often trigger episodes of abdominal discomfort.
- If overweight, try to reduce weight and avoid tight fitting clothing.
- If possible, avoid medicines that irritate the digestive tract, such as aspirin and other nonsteroidal anti-inflammatory drugs.

KEY POINTS

- Digestion is the process by which food and drink are broken down into their smallest parts so the body can use them to build and nourish cells and to provide energy.
- Peristalsis occurs throughout the length of the digestive tract and is responsible for keeping things moving.
- Stomach is subdivided into four regions which are: the Cardiac region, the Fundus, the Body and the Pylorus.
- A hormone called gastrin, controls the secretion of gastric juice. Protein molecules stimulate the endocrine cells of the stomach to secrete gastrin.
- The small intestine has a relatively small diameter, the intestinal walls are covered in wrinkles called rugae, which are themselves covered in millions of finger-like projections called villi.
- The large intestine is a thick tube which gets progressively narrower in diameter and it consists of four regions: the ceacum, colon, rectum, and anal canal.
- The liver helps maintain blood glucose levels in response to the pancreatic hormones insulin and glucagon.
- Lipogenesis is the metabolic process in which fats, composed of fatty acids and glycerol, are converted for storage in subcutaneous tissue and other storage depots.
- If energy and glucose levels are low, stored fat is converted back into glycerol and fatty acids by a process called lipolysis.
- The liver plays a vital role in detoxification and destruction of endogenous and exogenous harmful substances.
- The bulk of the pancreas is composed of pancreatic exocrine cells and their associated ducts. Pancreatic exocrine cells are arranged in grape-like clusters called acini.
- Secretin is released in response to acid in the small intestine, and stimulates the pancreas and bile ducts to release a flood of bicarbonate base, which neutralizes the acid.
- Destruction of the gastric or intestinal mucosal lining of the stomach by hydrochloric acid is a direct cause of peptic ulcer.
- Obesity or weight gain occurs when we eat more calories than our body uses up.
- Bulimia nervosa is an eating disorder in which a person may eat a lot of food at once and then try to get rid of the food by vomiting, using laxatives, or sometimes over-exercising.
- Anorexia is an emotional disorder which deals with perfectionism and a desire to control things by strictly regulating food and weight.
- Dyspepsia describes recurrent and persistent indigestion that occurs without an identifiable cause or abnormality of the digestive tract.

EXERCISE

A. Choose the correct answers in the following questions.

1. Which of the following convert's pepsinogen to the active form of pepsin in the stomach?

   a. Mucus b. Gastrin
   c. HCl d. Chief cells

2. Which of the following does NOT manufacture digestive juices?

   a. Liver b. Kidneys
   c. Stomach d. Pancreas

3. Which of the following is NOT a function of the liver?

   a. Storing food
   b. Manufacturing insulin
   c. Producing digestive juices
   d. Healing itself when it is damaged

4. Which of the following is **NOT** part of the accessory organs in the digestive system?

   a. liver b. pancreas
   c. large intestines d. acini

5. What is the function of the soft palate?

   a. To keep opening to nasal cavity open at all times
   b. To keep opening to nasal cavity open during swallowing
   c. To keep opening to nasal cavity closed during swallowing
   d. To keep opening nasal cavity closed at all times

6. An enzyme that acts only in an acidic medium is ______

   a. pepsin b. trypsin
   c. pancreatic amylase d. lipase

7. Absorption is maximum in the small intestine because of __________.

   a. the presence of villi b. its length
   c. its thin walls d. its thick walls

8. Appendix is a part of ________.

   a. ileum b. duodenum
   c. caecum d. colon

9. Bile juice is ______________.

a. alkaline b. acidic
c. semialkaline d. near acidic

10. The digestive juice that is almost neutral is ____________.

a. gastric juice b. bile juice
c. pancreatic juice d. saliva

11. Which of the following is **NOT** a function of the small intestines?

a. Receives secretions from the pancreas and liver
b. Completes digestion of nutrients
c. Absorbs products of digestion
d. Transports the residue to the anal canal

12. Which of the following statement is false regarding the function of the large intestines?

a. The only important secretion is mucous
b. Feces are formed and stored here
c. Main absorption is water and electrolytes
d. Digestive activity remain high in the large intestines

13. What disorder is associated with self-imposed starvation and an obsession with thinness?

a. Obesity b. Anorexia nervosa
c. Bulimia nervosa d. Binge eating

14. Which of the following is **NOT** a sign or symptom of anorexia nervosa?

a. Loss of menstrual cycles or periods
b. Low blood pressure
c. Increased sore throats and tooth decay
d. Increased dry, scaly, cold skin

B. Write short answers to the following questions.

1. What do you mean by physical digestion?
2. Name the cells that secretes mucus. What are the functions of mucus ?
3. Name the different parts of large intestine of humans in their natural sequence.
4. What is the advantage of emulsification of fats by bile juice?
5. Name the largest gland of human body and where is it located ?
6. What are the main symptoms of dyspepsia?
7. What measures are to be adopted for the diagnosis of anorexia nervosa?

C. Write in detail the answers of the following questions.

1. Explain the role of nervous system and gastrin hormone on the secretion of gastric juice.
2. Describe the mechanism of digestion in the stomach.
3. Describe the composition of bile and relate the constituents with respective roles.
4. Discuss the mechanism of digestion and absorption of food in the small intestine.
5. Explain the symptoms and treatment of bulimia nervosa?

Projects

- Identify some common digestive disorders and record some common household remedies being followed for their treatment. Give your justifications or other wise for the effectiveness of these remedies. Share your finding in the classroom.

Chapter

12 Circulation

At the end of this chapter students will be able to

- State the location of heart in the body and define the role of pericardium.
- Describe the structure of the walls of heart and rationalize the thickness of the walls of each chamber.
- Describe the flow of blood through heart as regulated by the valves.
- State the phases of heartbeat.
- Explain the role of SA node, AV node and Purkinji fibers in controlling the heartbeat.
- List the principles and uses of Electrocardiogram.
- Describe the detailed structure of arteries, veins and capillaries.
- Describe the role of arterioles in vasoconstriction and vasodilation.
- Describe the role of precapillary sphincters in regulating the flow of blood through capillaries. Trace the path of the blood through the pulmonary and systemic circulation (coronary, hepatic-portal and renal circulation).
- Compare the rate of blood flow through arteries, arterioles, capillaries, venules and veins.
- Define blood pressure and explain its periods of systolic and diastolic pressure.
- State the role of baroreceptors and volume receptors in regulating the blood pressure.
- Define the term thrombus and differentiate between thrombus and embolus.
- Identify the factors causing atherosclerosis and arteriosclerosis.
- Categorize Angina pectoris, heart attack, and heart failure as the stages of cardiovascular disease development.
- State the congenital heart problem related to the malfunctioning of cardiac valves.
- Describe the principles of angiography.
- Outline the main principles of coronary bypass, angioplasty and open-heart surgery.
- Define hypertension and describe the factors that regulate blood pressure and can lead to hypertension and hypotension.
- List the changes in life styles that can protect man from hypertension and cardiac problems.
- Describe the formation, composition and function of intercellular fluid.
- Compare the composition of intercellular fluid with that of lymph.
- State the structure and role of lymph capillaries, lymph vessels and lymph trunks.
- Describe the role of lymph vessels (lacteals) present in villi.
- Describe the functions of lymph nodes and state the role of spleen as containing lymphoid tissue.

Introduction

Materials in the human body need to be taken from one organ to another and to the tissues from where they are distributed to each and every cell of the body. This requires movement of material called circulation. It is a vital process of the body which is accomplished by a system called circulatory system.

The **circulatory system** is an organ system that transports nutrients gases, hormones, blood cells, nitrogen waste products, etc. to and from cells in the body to help fight diseases and help stabilize body temperature and pH in order to maintain homeostasis. This system is composed of the **cardiovascular system,** which distributes blood and the **lymphatic system**.which distributes lymph. Human beings and other vertebrates possess a closed cardiovascular system. In closed system the blood never leaves the network of arteries, veins and capillaries.

12.1 Human Blood Circulatory System

The most important means of transport of food, water, wastes and gases in human body is blood. For its circulation throughout the body, blood requires a system called blood circulatory system, also known as cardiovascular system. This system consists of heart and blood vessels.

Human Heart

Human heart (Greek word kardia) is muscular pumping organ. It is conical in shape and is generally about the size of your tightened fist. It is found on the left side of the thoracic (chest) cavity. Heart is covered by a tough double membrane called pericardium. This membrane protects the heart from over extension especially when we run or take a hard exercise. Both the membranes are slightly apart and in between them present a small cavity called pericardial cavity filled with a fluid, the pericardial fluid. Which lubricates the heart to ease the movement and protect the heart from any mechanical injury.

a. Structure of Heart

Heart consists of four chambers; two auricles (also called atria) and two ventricles. Heart is composed of cardiac muscles whch are specialized type of muscles keep working day and night, untiringly. Atria are smaller and thin walled, separated from each other by an inter-auricular septum. They form the anterior portion of the heart. Ventricles are larger, thick walled chambers, also separated by ventricular septum. Right atrium communicates with right ventricle through a valve called tricuspid valve (it is called tricuspid because it consists of three flaps of muscles) and left atrium opens into left ventricle through bicuspid valve (having two flaps).

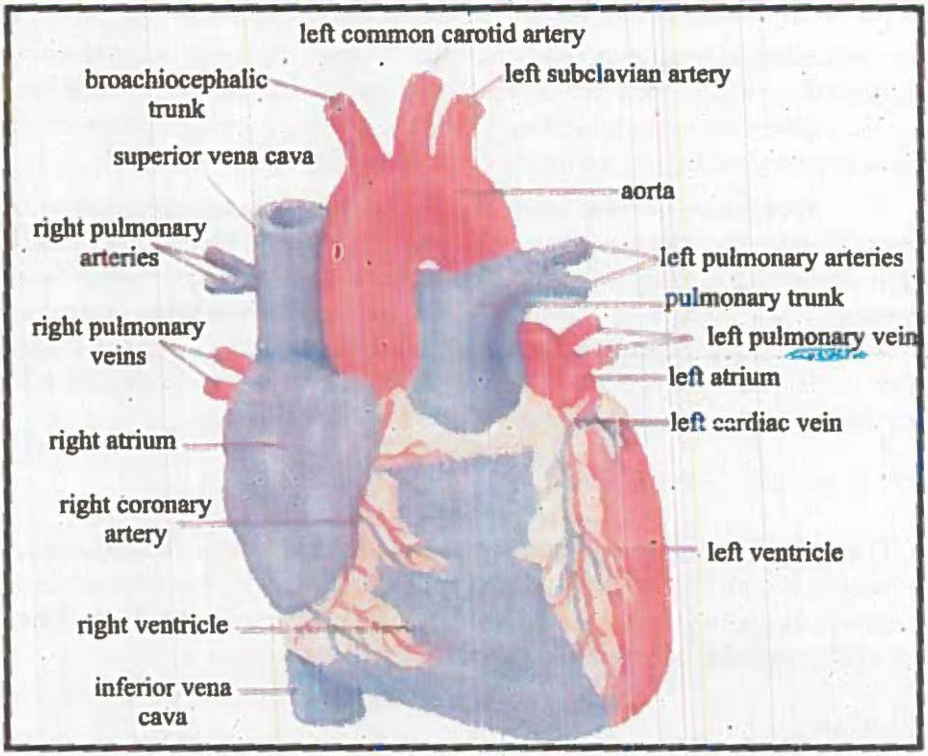


Fig: 12.1 Structure of heart

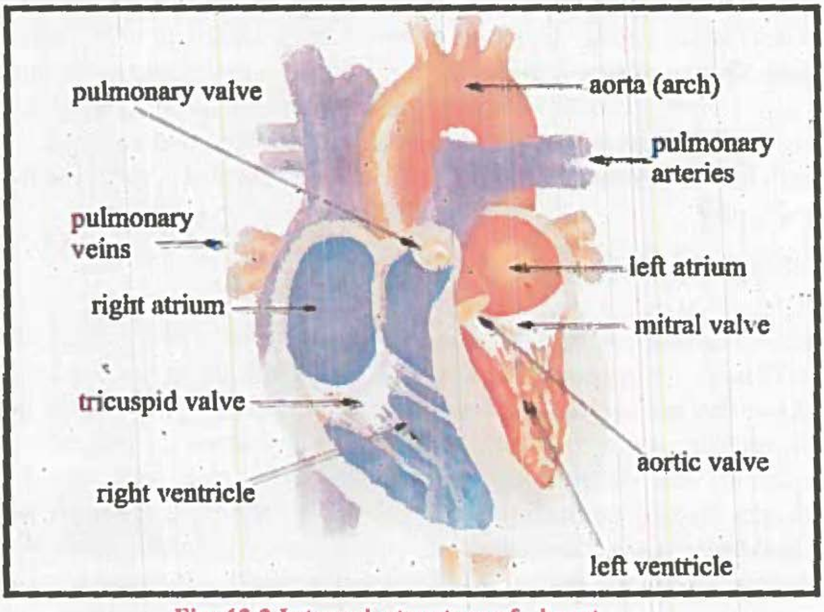


Fig: 12.2 Internal structure of heart

These valves control the blood flow and blood is allowed to flow only in one direction.

b. Function of Heart

The right atrium receives the deoxygenated blood through vena cava (largest vein) from the whole body. This happens when the heart relaxes and space is produced inside the atrium. The blood is forced to right ventricle through tricuspid valve. When the heart contracts the deoxygenated blood from right ventricle is pumped to the lungs through pulmonary arteries. (During this the tricuspid valve is kept closed preventing the back flow). After oxygenation the blood comes back to left atrium through pulmonary veins. (The semilunar valve in pulmonary vein allows the deoxygenated blood to go to lungs and prevent its back flow). From here via bicuspid value oxygenated blood is sent to the left ventricle. On contraction the oxygenated blood is pushed with full force into aorta (the largest artery) which distributes it to whole body through the smaller and smaller arteries.

Like other mammals, in human beings as well, the oxygenated and deoxygenated blood is completely separated. Deoxygenated blood remains on the right side of the heart and oxygenated on the left side of the heart. Valves play a very important role in this regard by preventing the back flow of blood.

12.1.1 Cardiac Cycle and Phases of Heartbeat

One contraction and one relaxation is called a cardiac cycle. Contraction of heart is termed as **systole** and relaxation as **diastole.** One complete cycle takes 0.8 seconds. The contraction and relaxation are cyclic and rhythmic. In first phase called diastole blood flows in all the four chambers passively. In second phase i.e. systole both the auricles contract together for about 0.1 second filling the ventricles completely with blood. Then in third phase the ventricles contract together for about 0.3 second pouring blood in to aorta and pulmonary artery.

Lub-dub Sound of Heart

The sound produced by heart is generally verbalized as lub-dub.Lub (first sound) is produced by closing of the AV valves during the contraction of ventricle in systole. The dub(second sound) is produced by closing of the semilunar valves in the beginning of diastole.

Normal rate of heart beat in a healthy human being is 72 beats per minute. This rate decreases when a person is resting or sleeping and increases to 120 beats per minutes during strong muscular exercise like running, swimming etc. and with some medicines like caffeine. Every time heart pours about 85 milliliters of blood into aorta with a great pressure.

Blood travels, in all different types of vessels, at different speeds. Speed is fastest in arteries, slower in arterioles and slowest in capillaries. From here it starts getting collected in venules. Its speed starts increasing in venules and faster again in veins.

The continuous working of heart is due to certain specialized structures like SA node (also called pacemaker), AV node and some specific type of fibers called purkinji fibers.

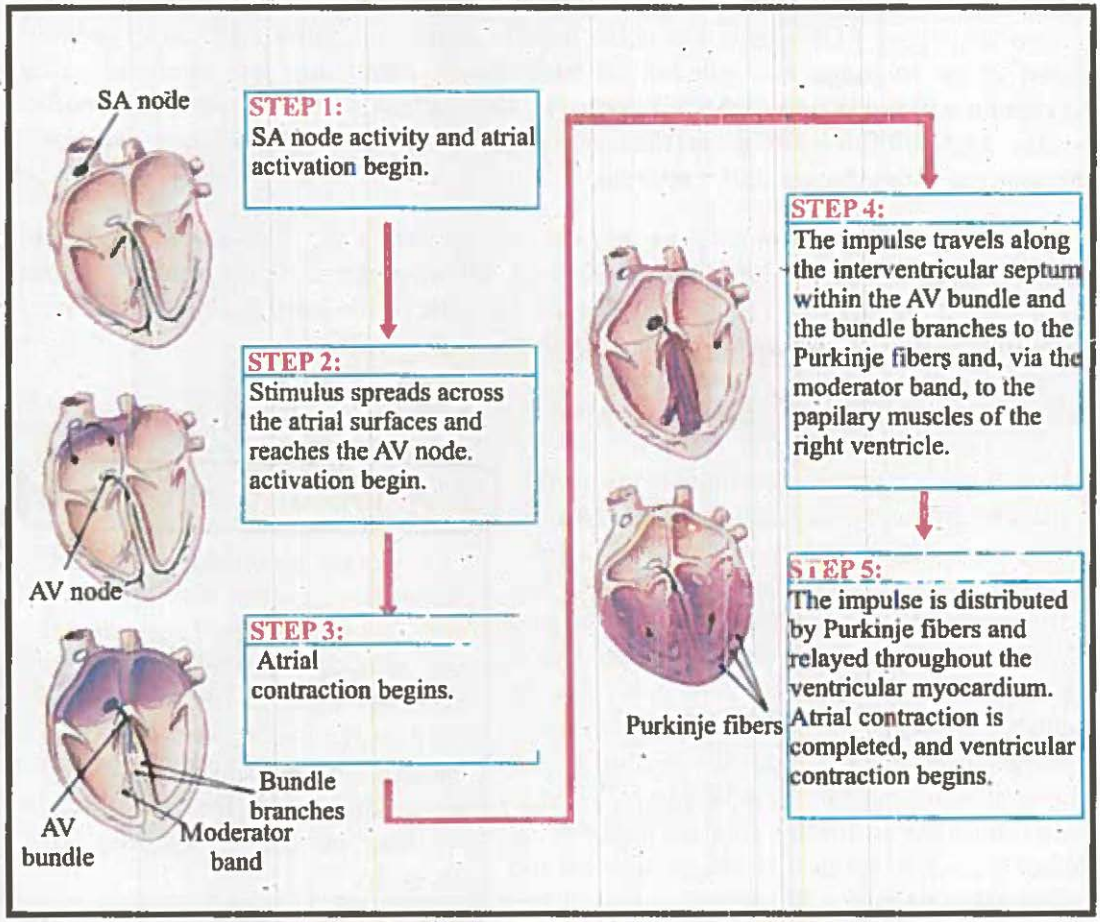


Fig: 12.3 Cardiac Cycle and phases of heartbeat

The pacemaker or SA node (sino-atrial node) is the impulse-generating (pacemaker) tissue located in the upper dorsal wall of the right atrium of the heart, near the entrance of the superior vena cava. SA node initiates the electrical impulses for heart beat and keeps the heart in motion.

The cells of the SA node generate electrical impulses faster than other cells and are responsible for the rest of the heart's electrical activity. SA node is thus sometimes called the primary pacemaker. Dysfunction of SA node causes disturbance in heart beat. Either it becomes very fast or very slow or some times a combination of both.

Another very important structure is AV node (atrio-ventricular node) which is the part of electrical control system of the heart. Its main function is to co-ordinates heart rate. It electrically connects atrial and ventricular chambers. It is an electrical relay station between the atria and the ventricles. Electrical signals from the atria must pass through the AV node to reach the ventricles. This node slows down the speed of the electrical signals to delay the contraction of ventricles until the atria are not fully contracted.

Purkinji fibers were discovered in 1839 by Jan Evangelista Purkinji. These fibers extend in the form of a branching tree in the heart and play an important role in its continuous working. Purkinji fibers are the extension of the autonomic nervous system. They are found in the inner wall of the ventricle just beneath the endocardium. These are specialized myocardial fibers which conduct electrical signals (nerve impulses) to different areas of heart to enable it to work in a coordinated way.

Artificial Pacemaker

In certain heart disorders natural pacemaker fails to generate impulses for heart beat. Then an artificial pacemaker is implanted near AV node. This pacemaker is an electronic device which automatically generates electric impulses after every 0.8 seconds.

12.1.2 Electrocardiogram (ECG)

The Electrocardiogram (ECG) is a electrocardiograph used for recording the electrical activity of the heart. For this purpose its electrodes are placed on the chest skin at specific locations. Doctors use it to monitor the electrical workings of the heart. The information is used to discover heart rate, arrhythmias, myocardial infarctions, atrial enlargements, ventricular hypertrophies, and bundle branch blocks etc.

The principle implied for recording the electrical impulse ECG is quite simple. When the overall electrical current of the heart goes towards a particular lead, it registers a positive deflection. Those that go away from the lead register a negative deflection. Those which are at 90 degrees or perpendicular to the vector of the lead registers 0, i.e. is seen as an isoelectric line.

Reading of ECG requires following conventions to be kept in mind.
Recording of the ECG is 25 mm/s which results in:

- 1 mm = 0.04 sec (or each individual block)
- 5 mm = 0.2 sec (or between 2 dark vertical lines)

Fig 12.4 a. Heart beat recorded through Electrocardiogram (ECG)

Fig: 12.4 b. Electrocardiogram

The voltage recorded from the leads is also standardized on the paper where

1 mm = 1 mV (or between each individual block vertically) This results in:

• 5 mm = 0.5 mV (or between 2 dark horizontal lines)

• 10 mm = 1.0 mv (this is how it is usually marked on the ECG's)

12.1.3 ECG Reading

The phases of a heart beat can also be divided into sections relating to the shape of the electrical signals produced when viewing the heart beat via an ECG (Electrocardiogram). This traces the electrical activity of the heart. The wave shape produced is called the QRS wave, with each part of the wave being labelled to help describe what is happening at each stage.

- TP Interval (Ventricular Diastole)

Atria and ventricles are relaxed; blood is flowing into the atria from the veins. As the atrial pressure increases above that of the ventricle, the AV valves open, allowing blood to flow into the ventricle

- P Wave (Atrial Systole)

The SA node fires and the atria contract causing atrial systole which forces all blood into the ventricles, empyting the atria.

- QR Interval (End of Ventricular Diastole)

The AV valves remain open as all remaining blood is squeezed into the ventricles. The electrical impulse from the SA node reaches the AV node which spreads the signal throughout the walls of the ventricles via specialised cells called bundles of His and Purkinje fibres. The R peak is the end of ventricular systole and the start of diastole.

- RS Interval (Ventricular Systole)

As the blood is now all within the ventricles and so pressure is higher here than in the atria, the AV valves close. The ventricles start to contract although pressure is not yet high enough to open the SL valves.

- ST Segment (Ventricular Systole)

Pressure increases until it equals Aortic pressure, when the SL valves open. The blood is ejected into the Aorta (and pulmonary artery) as the ventricles contract. At this time the atria are in diastole and filling with blood returning from the veins.

- T Wave (Ventricular Diastole)

Ventricles relax, the ventricular pressure is once again less than the aortic pressure and so the SL valves close. The cycle continues.

12.1.4 Blood Vessels:

The circulatory system consists of three types of vessels.

i. Arteries
ii. Capillaries
iii. Veins

i. Arteries

The vessels which carry blood away from the heart are called arteries. All the arteries transport oxygenated blood except pulmonary artery The only artery which carries deoxygenated blood from heart to the lungs is pulmonary artery. Arteries being very elastic resist flow of blood which is maintained through the very strong pushing force during ventricle contraction.

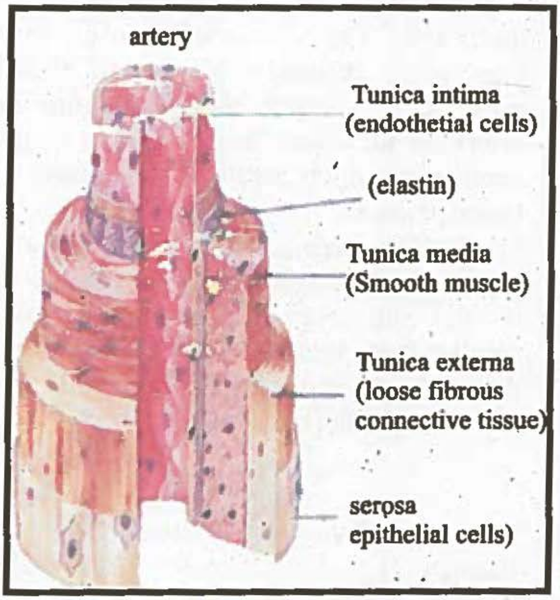


Fig: 12.5 Internal structure of artery

The wall of an artery is made of three layers.

The outer elastic layer, tunica externa, is made of areolar tissues and many layers of elastic fibers. These fibers give elasticity to the artery to expand and withstand the pressure of blood. Very large blood vessels require their own blood supply.

This is found in the form of a network of small arteries called the vasa vasorum (means vessels of vessels). This network is also found in tunica externa.

Middle layer, tunica media, is composed of circularly arranged smooth muscles and fewer elastic fibers. Inner layer, tunica interna or endothelium is comparatively thinner layer. It is composed of simple squamose epithelium and a thin layer of areolar connective tissue.

Arterioles are the smallest arteries with a diameter ranging from 3 mm to 10 micrometers. Larger arterioles have all three layers but smaller arterioles have only two; a thin layer of endothelium surrounded by a single layer of smooth muscle fibers.

Arterioles play an important role in **vasoconstriction** and **vasodilation.** Innervations (stimulus) of sympathetic nervous system cause contraction in the muscular layer of the arteriole, resulting in vasoconstriction of arteriole. This decreases the flow of blood into capillaries, resulting a rise in blood pressure. In contrast, the vasodilation of arterioles increases the blood flow in the capillaries which result in a decrease in blood pressure.

The largest artery of the body is aorta, which arises from left ventricle. It divides and re-divides into smaller and smaller branches which make arterioles. Arterioles finally break up into capillaries when they reach tissues.

Tidbit

Colour of the arteries appears to be red due to the bright red oxygenated blood flowing through them. Whereas due to deoxygenated blood veins appear to be bluish.

Do You Know?

The diameter of a capillary is little more than the RBC i.e. 7.5 µm. This decreases the blood flow and provides ample time for material exchange.

(ii) Capillaries

In circulatory system, the smallest blood vessels are capillaries. Their diameter is 8-10 micrometer. Their wall is only one cell thick and is very permeable. These very thin walls of the capillaries allow the exchange of water, oxygen, dissolved nutrients and waste products etc. in between capillaries and the cells of the tissue.

A capillary is so thin that only one RBC passes through it at a time, releasing its oxygen by diffusion to the cells. The very small diameter of the capillaries provides ample time to the blood for exchange of materials. After releasing nutrients to tissues, capillaries start joining to form venules.

Flow of blood in the capillaries is adjusted by the precapillary sphincters. A precapillary sphincter is a band of smooth muscle that encircles each capillary branch at the point where it branches off from the arteriole. Contraction of the precapillary sphincter can close off the branches stopping the blood flow. If the sphincter is damaged or can not contract, blood can flow into the capillary bed at high pressures. When capillary pressures are high, fluid passes out of the capillaries into the interstitial space and edema or fluid accumulation is resulted.

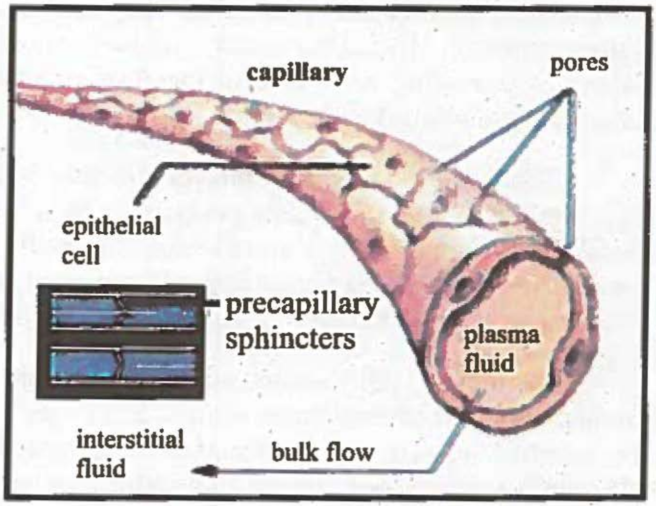


Fig: 12.6 Internal structure of capillary

(iii) Veins

Veins are the vessels which bring the blood back from different organs of the body towards heart. All the veins transport deoxygenated blood except for pulmonary vein which brings oxygenated blood.

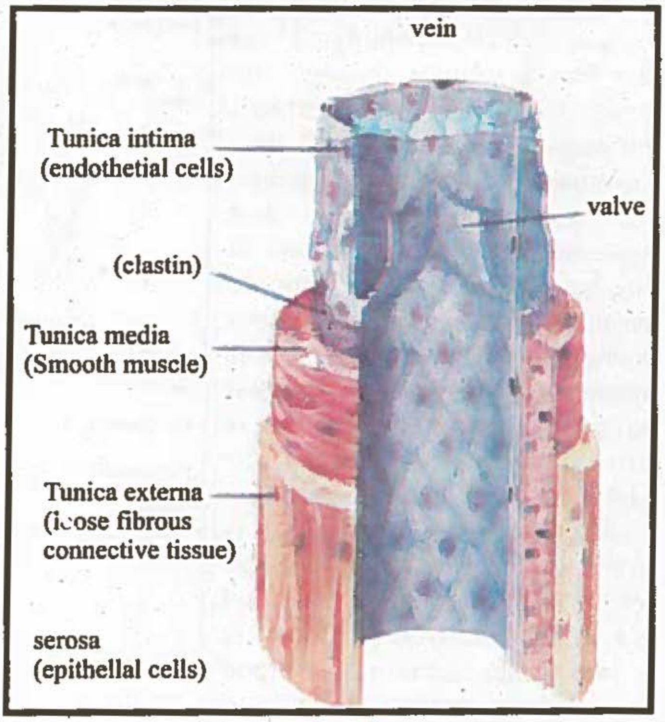


Fig: 12.7 Internal structure of a vein

Walls of the vein are composed of the same three layers but the middle layer is thinner as compared to that of arteries. They are less elastic as they do not have to bear systolic pressure. Most of the volume of blood is contained in veins. The reason is that, instead of providing resistance in the flow of blood like arteries, they expand to accumulate additional volume of blood.

The average pressure in the veins is only 5-10 mm Hg (In arteries it is 100mm Hg). The Veins have a very low pressure of blood which is not sufficient to take the blood to the heart, they keep valves which allow the flow of blood in one direction i.e. towards heart and prevent back flow. Veins passing through skeletal muscles get help to return the blood to the heart from the massaging action of the skeletal muscles.

Venules (8-100 micrometer in a diameter) after coming out of tissues start joining with each other to make veinlets and larger veins. The largest veins in the body are; superior vena cava which brings deoxygenated blood from head and upper region of the body and inferior vana cava which brings blood from lower parts of the body.

12.1.5 Path of Blood through Pulmonary and Systemic Circulation

When a heart contracts and forces blood into the blood vessels, there is a certain path that the blood follows through the body. The blood moves through pulmonary circulation and then continues on through systemic circulation. Pulmonary and systemic are the two circuits in the two-circuit system of higher animals with closed circulatory systems. Humans and other mammals have two-circuit circulatory systems: one circuit is for pulmonary circulation (circulation to the lungs; pulmon = lungs), and the other circuit is for systemic circulation (the rest of the body). As each atrium and ventricle contract, blood is pumped into certain major blood vessels, and from there, continues through the circulatory system.

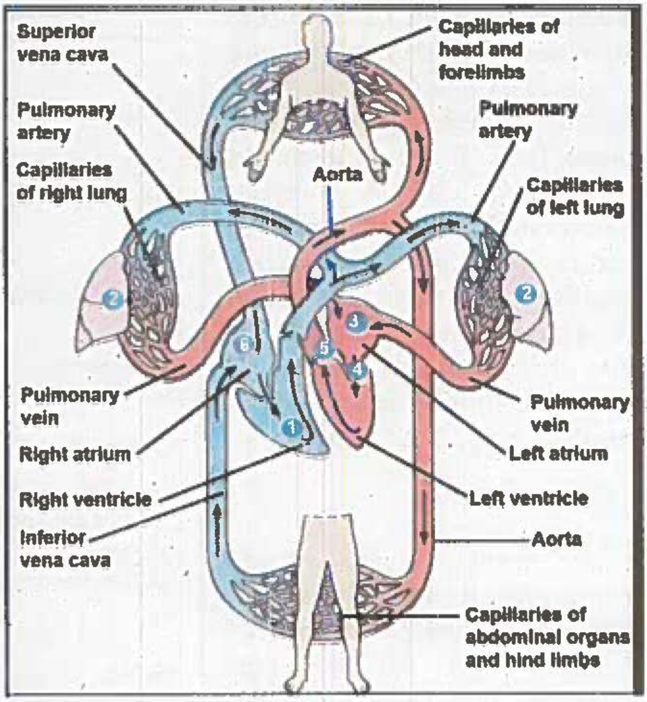


Fig: 12.8 Circulatory plan

12.1.6 Exchange of Material

The most important function of blood circulatory system is to transport oxygen and nutrients to the cells of the tissue and remove the metabolic waste products from the tissues and transport them back to the organs responsible for their excretion.

In the alveoli of the lungs oxygen binds to the heme part of the haemoglobin, filled in RBCs. Blood also absorbs nutrients, especially glucose, from villi found in the walls of the small intestine and comes back to the heart.

This blood is pumped into the aorta with full force of the contracted ventricle. From aorta it moves into branching arteries and then arterioles. When this blood, loaded with oxygen and nutrients, reaches capillaries, due to the low concentration of these materials in tissues, oxygen and nutrients diffuse out of the walls of capillaries and enter tissues. The concentration of waste material is more in tissues so they diffuse into the capillaries.

> **For Your Information**
>
> Blood is pumped to the body (via aorta) with great pressure to confirm its distribution to the farthest parts of the body like hairs on head and nails of feet. On the other hand the blood is pumped to the lungs (via pulmonary artery) with lesser pressure due to which it moves slowly through the alveoli of the lungs, getting sufficient time for oxygenation.

Due to the pressure of blood some water also oozes out of the capillaries as interstitial fluid. This water increases the osmotic pressure outside the capillaries. Therefore, at venous end of the capillaries water again diffuses back to the capillaries along with dissolved waste products.

12.1.7 Control of the Capillary Beds

It has been estimated that an adult human being has some 60,000 miles of capillaries with a total surface area of some 800–1000 m^2 (an area greater than three tennis courts). The total volume of this system is roughly 5 liters, the same as the total volume of blood in human body. However, if the heart and major vessels are to be kept filled, all the capillaries cannot be filled at once. So a continual redirection of blood from organ to organ takes place in response to the changing needs of the body. During vigorous exercise, for example, capillary beds in the skeletal muscles open at the expense of those in the viscera.

The reverse process occurs after a heavy meal. The table 12.1 shows the distribution of blood in the human body at rest and during vigorous exercise. Note the increase in blood supply to the working organs (skeletal muscles and heart). The increased blood supply to the skin aids in the dissipation of the heat produced by the muscles. The total blood flow during exercise increases because of a more rapid heartbeat and also a greater volume of blood pumped at each beat.

Table 12.1 Showing approximate blood flow in milliliter/ minute.

Organ	At Rest	During Strenuous Exercise
Heart	250	750
Kidneys	1,200	600
Skeletal Muscles	1,000	12,5000
Skin	400	1,900
Viscera	1,400	600
Brain	750	750
Other	600	400
Total	5,600	17,500

12.1.8 Blood Pressure (B.P)

We know that rhythmic pumping of the heart pours the blood in to the arteries. This pulsation can easily be felt in those arteries (like radial artery) which are near the surface of the skin and we generally call it pulse. The throb we feel (as pulse) is due to the pressure of the blood which makes the elastic layer of arteries to expand rhythmically allowing blood to pass through.

The force per unit area that blood exerts on the inside walls of a blood vessel is called blood pressure. It is measured in millimeter of mercury (mm Hg). It is measured with the help of an instrument called sphygmomanometer. Blood pressure is of two types

- **Systolic blood pressure** which is felt during the ventricular contraction
- **Diastolic blood pressure** which is felt during ventricular relaxation.

Systolic B.P is greater than the diastolic pressure. The B.P is generally expressed as a ratio in which numerator shows the systolic and denominator depicts the diastolic B.P. An average, healthy adult human being has a B.P. of 120 / 80 mmHg. With increasing age the normal value of BP also increases due to decrease in the elasticity of the blood vessels.

The blood pressure is generated by the contraction of the left ventricle. Therefore, pressure is highest in the aorta. As the arteries branch and travel greater distances from the heart the blood pressure decreases. In capillaries the difference between systolic and diastolic pressure disappears. In capillaries the B.P. is about 40 mm Hg. It decreases to less than 20 mm Hg when the blood leaves arteries and further drops in venuoles. The pressure of the blood is minimum when it enters the right atrium from upper and lower vena cavae.

Measuring blood pressure

To measure B. P. the doctor wraps a cuff around the arm of the patient. Then this cuff is inflated with the help of a pump. This inflation compresses the brachial artery against the muscles around the humerus bone, temporarily stopping the blood flow. The doctor places a stethoscope near the compressed artery and start releasing air gradually from the cuff. Now the doctor concentrates to listen to the sound of the pulse. When the first pulsation is heard, through the stethoscope. the sphygmomanometer is read. This reading shows the systolic blood pressure. The second reading is taken when the sound of the pulsation stops (because due to further decrease in air pressure in the cuff blood start flowing evenly through the artery). This reading depicts diastolic blood pressure. Nowadays different types of automatic digital BP apparatus are also available but the manual method is more reliable for accurate reading.

Table 12.2 Blood pressure in different blood vessels

Name of Vessel	Systolic B.P.	Diastolic B.P	B.P
Aorta	120	80	
Arteries	102	60	
Arterioles	60	45	
Capillaries	-	-	40
Venules	-	-	20
Veins	-	-	10
Vena cava	-	-	0

Certain sensors (nerve endings) are located in the blood vessels of the human body **called Baroreceptors** (or baroceptors). They detect the pressure of blood flowing through them, and can send messages (signals) to the central nervous system to increase or decrease total peripheral resistance and cardiac output. They work as short term blood pressure regulation mechanism.

Baroreceptors detect the amount of stretch of the blood vessel walls, and send the signal to the nervous system in response to this stretch.

Baroreceptors can be divided into two categories

a) High pressure arterial baroreceptors

b) Low pressure baroreceptors (also known as cardiopulmonary or volume receptors).

High pressure arterial baroreceptors are present in the aortic arch and the carotid sinuses of the left and right internal carotid arteries. The baroreceptors found within the aortic arch enable the examination of the blood being delivered to all the blood vessels via the systemic circuit, and the baroreceptors within the carotid arteries monitor the blood pressure of the blood being delivered to the brain.

Low pressure baroreceptors are found in large systemic venal caval veins and in the walls of the right atrium of the heart. The low pressure baroreceptors are involved with the regulation of blood volume. The blood volume determines the mean pressure throughout the system, in particular in the venous side where most of the blood is held.

The low pressure baroreceptors have both circulatory and renal effects, they produce changes in hormone secretion which have profound effects on the retention of salt and water and also influence intake of salt and water. The renal effects allow the receptors to change the mean pressure in the system in the long term.

12.2 Cardiovascular Disorders

Many disorders are associated with the circulatory system. Some of the significant are the following.

12.2.1 Thrombosis and Embolism

Thrombosis is a Greek word which means **blood clot**. It is formed by the aggregation of platelets inside the vessels. The disorder in which a person generates a thrombus in a vessel is called **thrombosis.** A thrombus in a blood vessel is very painful. A thrombus in a large blood vessel decreases blood flow through that vessel but in a small blood vessel it may completely stop the blood flow resulting in the death of tissue supplied by that vessel. Risk of thrombosis increases in certain conditions like atrial fibrillation, heart valve replacement, a recent heart attack, extended periods

Generally bed ridden patients and people like barbers who keep standing for hours as part of their daily routine suffer from this disorder. A thrombus which dislodges and becomes free-floating is termed as an embolus. The term embolus was coined by Rudolph Carl Virchow in 1848. An embolus migrates from one part of the body, through blood circulation, and causes a blockage of a blood vessel in another part of the body.

In thrombo embolism, the thrombus from a blood vessel is completely or partially detached from the site of thrombosis. The blood flow will then carry the embolus (via blood vessels) to various parts of the body where it can block the lumen and causes vessel obstruction or occlusion. One of the most commonly recognized problems caused by the embolus is called **coronary thrombosis**. In this case, the thrombus blocks a coronary artery causing myocardial infarction commonly known as a heart attack. Even worse situation appears when the thrombus blocks an artery to the brain. This is commonly called as **stroke.** A stroke may result in sudden death or paralysis of the body.

12.2.2 Atherosclerosis and Arteriosclerosis

a. Atherosclerosis: It **(Gr. Athere = porridge, skeleoris = hardening)** is the condition in which the wall of artery thickens as a result of deposition of fatty materials such as cholesterol. It develops from low-density lipoprotein molecules (LDL) becoming oxidized by free radicals.

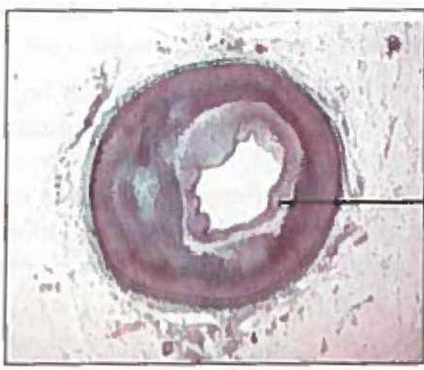


Fig: 12.9 A coronary artery with atherosclerosis. The lumen has been narrowed to a greater extant

When oxidized LDL comes in contact with the wall of an artery, a series of reactions occur to repair the damage to the artery wall caused by oxidized LDL. The body's immune sends specialized white blood cells called macrophages and T-lymphocytes to absorb the oxidized-LDL, forming specialized foam cells.

Unfortunately, these white blood cells are not able to process the oxidized-LDL. They grow and then rupture, depositing a greater amount of oxidized cholesterol into the artery wall. This triggers more white blood cells and the cycle continues. As a result, the artery becomes inflamed. The cholesterol plaque causes the muscle cells to enlarge and form a hard cover over the affected area. This hard cover causes the artery lumen to become narrow. Narrowing of artery reduces the blood flow and increases blood pressure. Atherosclerosis typically begins in early adolescence, and is usually found in most major arteries, yet is asymptomatic and not detected by most diagnostic methods until it grows to a serious threat to health. There are various anatomic, physiological and behavioral factors which increase the risk for atherosclerosis. Factors add to each other multiplicatively, with two factors increasing the risk of atherosclerosis fourfold. Studies show that Hyperlipidemia (High level of fats in blood), hypertension and cigarette smoking together increases the risk seven times.

Instead of medication the first method of treatment advised by the doctors, throughout the world, is to stop smoking, change feeding habits and choice of foods and practicing daily exercise or at least daily walk. If these methods do not work, medicines are usually the next step in treating cardiovascular diseases. If atherosclerosis leads to symptoms like angina pectoris then it becomes necessary to start medication.

Physical treatments which are helpful in the short term include **angioplasty** procedures that may include **stents** to physically expand narrowed arteries and major invasive surgery, such as **bypass surgery** to create additional blood supply connections that go around the more severely narrowed areas.

b. Arteriolosclerosis: It is any hardening, stiffening or loss of elasticity of arterioles. It is often due to hypertension. The most common sites for arteriosclerosis are arteries in the brain, kidneys, heart, abdominal aorta or legs. Symptoms of arteriosclerosis vary according to the arteries which are affected. Leg pain when exercising might indicate peripheral arterial disease. Sudden weakness or dizziness could be caused by an obstruction in the carotid artery in the neck, which produces stroke-like symptoms. Chest pain or symptoms of a heart attack might indicate obstruction of the coronary arteries.

Risk factors for arteriosclerosis are more or less similar as that of atherosclerosis. They include smoking, obesity, high blood pressure, high serum cholesterol, stress, and diabetes. A family history of early heart disease is also a risk factor for developing arteriosclerosis.

12.2.3 Congenital Heart Problem

A congenital heart defect is a defect in the structure of the heart and large blood vessels of a newborn baby. Most of these heart defects either obstruct blood flow in the heart or vessels near it or cause blood to flow through the heart in an abnormal pattern. Defect may also occur affecting the heart rhythm.. Heart defects are among the most common birth defects and are the leading cause of birth defect-related deaths. Congenital heart disease can be categorized in to different types. In some babies right ventricle or the left ventricle fails to develop. As a result only one side of the heart pumps the blood the body and lungs. This defect is called Hypoplasia of the heart which is rare but is the most serious form of congenital heart defect.

Other type of defect may be called as Obstruction defects. Obstruction defects occur when heart valves, arteries, or veins are abnormally narrow or blocked. Common obstruction defects include blockage of pulmonary valve, aortic valve and bicuspid aortic valve. Any narrowing or blockage can cause heart enlargement or hypertension.

The most common among the congenital heart defects are the defects in the septa of the heart. The septum is a wall of tissue which separates the left side of the heart from the right side of the heart. The defect may be in the septum between the atria or the septum between the ventricles. Due to this defect the blood flows from the left side of the heart to the right side. This mixing of oxygenated and deoxygenated blood reduces the overall efficiency of the heart. Septal defects may or may not cause cyanosis depending on the severity of the defect. Some times the defect is so minor that it requires no treatment and is corrected by itself with the passage of time and increasing age. Major defects require medication and surgery.

12.2.4 Blue Baby or Cyanosis

One of the effect of congenital heart defect is the birth of blue babies, a physiological condition called cyanosis. The reason for the appearance of blue colour is the formation of carboxyhaemoglobin instead of oxyhaemoglobin in the blood because of limited availability of oxygen. During the embryonic life , heart of the foetus start beating after four month of gestation. In the heart of the foetus , an opening, "foramen ovale" connects the right atrium with left atrium. The blood passes from right atrium to the left without passing through lungs. The reason for this bypass is that the supply of oxygen to the foetus is from the blood of the mother through placenta (and not by lungs).

After the birth the foramen ovale closes spontaneously but in some babies it does not close completely. When the baby exerts force during crying and movement the deoxygenated blood from the right atrium enters the left atrium through the partially opened foramen.

When the haemoglobin of this venous, deoxygenated blood turns to carboxyhaemoglobin, it imparts blue discoloration to the skin , lips, ears and other organs of the baby, resulting in cyanosis or blue baby.

Fig: 12.10 Blue baby

12.2.5 Hypertension

Hypertension is a chronic medical condition in which a person suffers persistently from high blood pressure. As you studied under the section of blood pressure the normal BP of a healthy normal adult is 120/80 mm Hg and with increasing age the normal BP also increases. For a normal adult a mercury reading of 130/90 is considered hypertensive. For a women of above forty five years of age BP of 160/95 is considered hypertensive whereas for a man this limit is 140/95. Hypertension can be classified as

- Essential or primary hypertension
- Secondary hypertension

Primary or essential hypertension means that no medical cause is found to explain the raised blood pressure. Secondary hypertension indicates that the high blood pressure is a result of another condition, such as kidney disease, Cushing's syndrome, (a disorder in which both adrenal glands can overproduce the hormone cortisol) or tumours or due to medication such as Ibuprofen and steroids.

For Your Information

Studies have shown that reduction of the blood pressure by 5–6 mmHg can decrease the risk of stroke by 40% and of coronary heart disease by 15–20%. This also reduces the likelihood of dementia, heart failure and mortality from vascular disease to a greater extent.

Persistent hypertension is one of the risk factors for strokes, heart attacks, heart failure and arterial aneurysm, and is a leading cause of renal (kidney) failure.

Prevention and Treatment of Hypertension

Hypertension can be treated by:

- Weight reduction
- regular aerobic exercise
- Reducing dietary intake of sugar and table salt
- By taking a diet rich in fruits and vegetables and low-fat or fat-free dairy foods
- By discontinuing use of tobacco and alcohol
- Reducing stress and tensions
- severe cases antihypertensive medicines are also used.

Hypotension is the opposite of hypertension. **Hypotension** is abnormally low blood pressure. It is considered as a physiological state, rather than a disease. Not always but most often hypotension is associated with shock. Hypotension can also be life-threatening. The initial symptom of hypotension is dizziness. If the blood pressure is sufficiently low, fainting and often seizures will occur. Patients with hypotension also complain chest pain, shortness of breath, irregular heartbeat and headache.

The most common cause of producing hypotension is reduced blood volume in the body. This reduction in the volume of blood can result from hemorrhage (blood loss) insufficient fluid intake (as in starvation), excessive fluid losses from diarrhea or vomiting, or is often induced by excessive use of diuretics. Some medicines can also produce hypotension as a side effects.

12.2.6 Angina Pectoris

Angina pectoris or simply **angina** is a severe, radiating chest pain due to the lack of blood supply to the heart muscle, generally due to obstruction or spasm of the coronary arteries. Main cause of angina, is atherosclerosis of the cardiac arteries. pain of angina starts from left side of the chest and radiates to left shoulder, neck and sometimes cerebral region.

Angina is the first alarm of the body to show that something is going wrong with the heart. Those who realize and start precautionary measures and bring a change in their lifestyle and diet, they lead a successful and active life. Those who do not care and continue with their life style generally come across a heart attack. It is a common experience that people survive in first two attacks but mostly third attack is fatal and results in heart failure.

Treatment of Cardiovascular disorders:

In the above description you studied many ways to prevent and minimize different cardiovascular diseases. These ways help the patients to certain extent but sometimes doctors advise major or minor surgery or some other modern ways to provide relief to the patient. Among these methods some are

a. Angiography
b. Angioplasty
c. Coronary bypass
d. Open heart surgery

a. Angiography

Angiography is a test that uses an injection of a liquid dye to make the arteries easily visible on X-rays. An angiogram is commonly used to check the condition of blood vessels. There are alternatives nowadays to angiography, such as CT scan, MRI scans, nuclear scans, and ultrasound scans, which often produce information as accurate and useful as angiograms.

b. Angioplasty

One method of treatment of a blocked artery is angioplasty. The term angioplasty is a the combination of two Greek words; *aggeîos* meaning "vessel" and *plastós* meaning "formed" or "moulded". It is the technique of mechanically widening a narrowed or obstructed blood vessel; typically as a result of atherosclerosis. In this treatment a balloon-tip catheter is passed in the artery. At the site where the lumen is narrowed due to blockage, the balloon is inflated to a fixed size using water pressures some 75 to 500 times more than normal blood pressure (6 to 20 atmospheres). This high pressure removes the blockage and opens the artery.

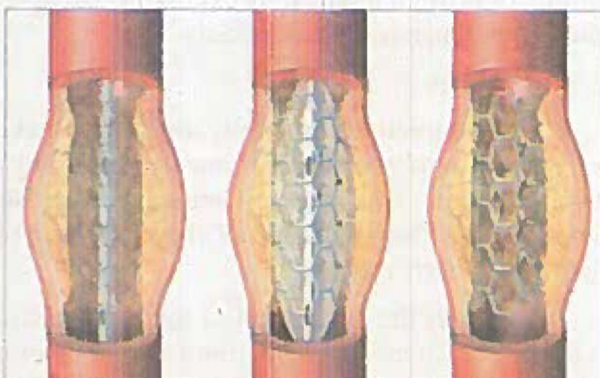


Fig: 12.11 Angioplasty through stent

Sometimes, to ensure that the lumen remains open, a metallic ring called stent is placed there at the site. This stent remains there as part of the artery and ensures that the artery remain open.
The angioplasty is not restricted to the coronary arteries.

Now other arteries which get narrowed by atherosclerosis are cleared and opened by this procedure generally called peripheral angioplasty. This type of angioplasty includes **renal** artery angioplasty, Carotid angioplasty, Cerebral arteries angioplasty etc.

c. Coronary bypass or Open heart surgery

Another treatment is called **Coronary artery bypass surgery (also called coronary by pass or simply bypass)**. In this treatment a vessel is taken from some other part of the body and is grafted from aorta to the coronary artery system. This vessel starts supplying blood to the heart muscles by passing the original blocked artery.This surgery is usually performed with the heart stopped, necessitating the usage of cardiopulmonary bypass; techniques are available to perform bypass on a beating heart, so-called "off-pump" surgery.

For Your Information

History of coronary artery bypass

The first coronary artery bypass surgery was performed in the United States on May 2, 1960 at the Albert Einstein College of Medicine, Bronx Municipal Hospital Center by a team led by Dr. Robert Goetz and the thoracic surgeon, Dr. Michael Rohman with the assistance of Dr. Jordan Haller and Dr. Ronald Dee. They used internal mammary artery as the donor vessel and was anastomosed to the right coronary artery.In 1967 Dr. René Favaloro introduced a new technique in which a saphenous vein (present in lower part of leg) was used to replace the blocked coronary artery. He later began to use the saphenous vein as a bypassing channel and become instantly successful. This is the typical bypass graft technique we know today.

A successful graft typically lasts around 10–15 years which means this process sufficiently improves the chances of survival of a patient suffering from atherosclerosis.

d. Open Heart Surgery

Any surgery where the chest is opened and surgery is performed on the heart muscle, valves, arteries, or other heart structures is termed as open heart surgery. The term "open" refers to the opening of chest and not the heart itself. The heart may or may not be opened, depending on the type of surgery. As for sometime heart is non-functional a heart-lung machine (also called cardiopulmonary bypass) is usually used during conventional open heart surgery. It helps provide oxygen-rich blood to the brain and other vital organs. The definition of open heart surgery has become confusing with new procedures being performed on the heart through smaller incisions. There are some new surgical procedures being performed that are done with the heart still beating and is generally termed as beating heart surgery.

For Your Information

The first successful surgery of the heart, performed without any complications, was by Dr. Ludwig Rehn of Frankfurt, Germany, who repaired a stab wound to the right ventricle on September 7, 1896. It was soon discovered that the surgery is better done with a bloodless and motionless environment, which means that the heart should be stopped and drained of blood. The first successful intracardiac correction of a congenital heart defect using hypothermia was performed by Dr. C. Walton Lillehei and Dr. F. John Lewis at the University of Minnesota on September 2, 1952. In all the major Govt hospitals like. Lady reading Hospital, Peshawar Hayatabad Medical complex, Ayub Teaching Hospitals Abbottabad cardiology centres are providing quality treatment for cardiac patients.

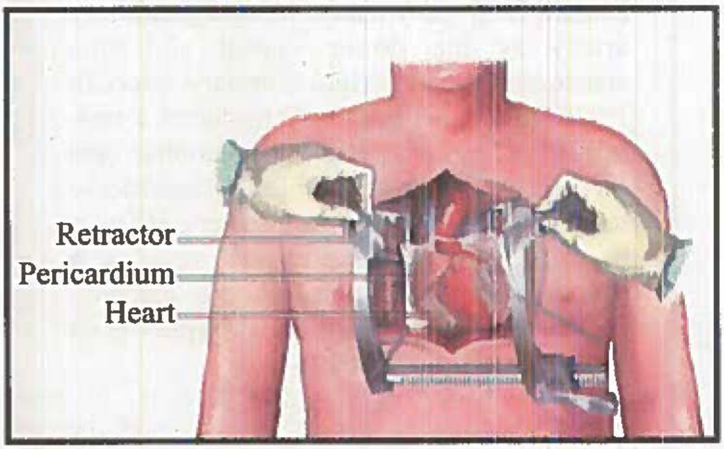


Fig: 12.12 Open heart surgery in process

12.3 Lymphatic System

The **lymphatic system** is a network of vessels found in vertebrates that carry a milky fluid called lymph. It also includes the lymphoid tissue through which the lymph travels. This system transports and returns materials from the tissues of the body to blood. In 1652 the lymphatic ducts in the liver were first described by a Swedish Olaus Rudbeck (1630–1702) and the very next year it was Thomas Bartholin who described these vessels in the whole body and gave them the name of lymphatic vessels.

Lymph vessels, at certain points , have masses of connective tissues called **lymph nodes.** These node (more than 100 in human body) are present in the armpits, groin and neck region. These are the sites of lymphocyte production and storage. They act as barriers to infection by filtering out and destroying toxins and germs. The largest body of lymphoid tissue in the human body is the spleen.

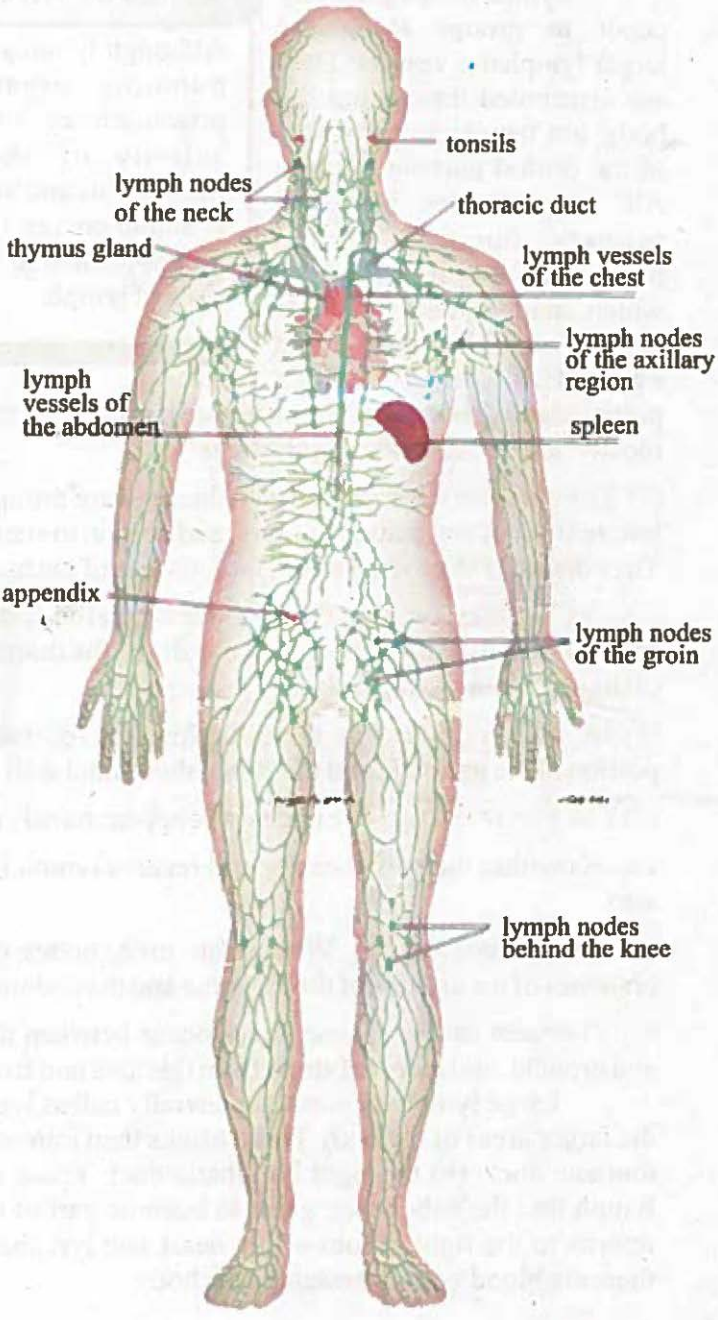


Fig: 12.13 Lymphatic System in a Human body

a. Position of lymph node

> **For Your Information**
>
> Although lymphatic system does not posses any pumping organ like heart to provide pressure/force to transport material but the activity of skeletal muscles, breathing movements and movement of the viscera provide it ample energy to move the fluid upward. The valves present in lymph vessels prevent the back flow of lymph.

Lymph nodes generally occur in groups along the larger lymphatic vessels. They are distributed throughout the body, but they lack the tissues of the central nervous system. All lymph nodes have the primary function of the production of lymphocytes, which help defend the body against microorganisms and against harmful foreign particles and debris from lymph before it is returned to the blood stream. The nodes are mostly located in following six areas:

(1) The cervical region: Nodes in this area are grouped along the lower border of the jaw, in front of and behind the ears, and deep in the neck along the larger blood vessels. They drain the skin of the scalp, face, tissues of the nasal cavity, and the pharynx.

(2) The axillary region: These nodes are in the underarm region and receive lymph from vessels that drain the arm, the walls of the thorax, the breast, and the upper walls of the abdomen.

(3) Inguinal region: The nodes in this area receive lymph from the legs, the outer portion of the genitalia and the lower abdominal wall.

(4) The pelvic cavity: The nodes here appear mostly along the paths of the blood vessels within the pelvic cavity and receive lymph from the lymphatic vessels in the area.

(5) Abdominal cavity: Within this area, nodes occur in chains along the main branches of the arteries of the intestine and the abdominal aorta

(6) Thoracic cavity: These nodes occur between the lungs and along the windpipe and bronchi, and receive lymph from this area and from the internal wall of the thorax.

Large lymphatic vessels generally called lymphatic trunks drain lymph from the larger areas of the body. These trunks then join one of two collecting ducts: (a) the thoracic duct (b) the right lymphatic duct. These collecting ducts finally drain the lymph into the subclavian veins to become part of the plasma, just before the blood returns to the right atrium of the heart. The lymphatic vessels are present wherever there are blood vessels present in the body.

They are joined by a capillary system. When the blood passes through arteries , veins and capillaries the water along with certain salts, some plasma proteins etc ooze out in tissue spaces. This fluid is called **interstitial fluid**. Interstitial fluid bathes the cells in the tissue space. From here this fluid is collected in the fine, very permeable, blind ended capillaries of lymphatic system in the form of lymph which join to make larger vessels. The lymphatic vessels transport this excess fluid to the end vessels without the assistance of any "pumping" action. This system is very important for the distribution of fluids and nutrients in the body, because it drains excess fluids and protein so that tissues do not swell up. Our body also eliminates the products of cellular breakdown and bacterial invasion through this system. It filters out organisms like bacteria, viruses and fungi that cause disease, produces certain white blood cells called lymphocytes.

b. Spleen as lymphatic organ

The spleen is an effective in protecting the body by clearing worn out red blood cells and other foreign bodies from the bloodstream.The spleen contains lymphocytes and macrophages, which can engulf and destroy bacteria, dead tissue, and foreign matter.

c. Lymphatic system and cancer

The study of lymphatic drainage of various organs is important in diagnosis, prognosis, and treatment of cancer. Lymph nodes can trap the cancer cells. If they are not successful in destroying the cancer cells the nodes may become sites of secondary tumors.

d. Diseases of lymphatic system

Problems with the system can impair the body's ability to fight infections. Hodgkin's disease is an enlargement of the lymph nodes in the neck.Pressure on adjoining organs and nerve endings can result in a dysfunction of vital organs or in paralysis.

KEY POINTS

- The circulatory system is an organ system thah transports nutrients gases, hormones, blood cells, nitrogenous waste products, etc. to and from cells in the body to helps to fight diseases and help stabilize body temperature and pH to maintain homeostasis.
- One contraction and one relaxation is called a cardiac cycle. Contraction of heart is termed as systole and relaxation as diastole.
- The pacemaker or SA node is the impulse-generating tissue located in the upper dorsal wall of the right atrium of the heart, near the entrance of the superior vena cava.
- Electrocardiograph (ECG) is a medical device used for recording the electrical activity of the heart.
- A capillary is so thin that only one RBC passes through it at a time, releasing its oxygen by diffusion to the cells. The very small diameter of the capillaries provides ample time to the blood for exchange of materials.
- Most of the volume of blood is contained in veins. The reason is that, instead of providing resistance in the flow of blood like arteries, they expand to accumulate additional volume of blood.
- The force per unit area that blood exerts on the inside walls of a blood vessel is called blood pressure.
- Blood pressure is of two types: Systolic blood pressure which is felt during the ventricular contraction. Diastolic blood pressure which is felt during ventricular relaxation.
- Certain sensors (nerve endings) are located in the blood vessels of the human body called Baroreceptors (or baroceptors). They detect the pressure of blood flowing through them,
- Thrombus is a blood clot which is formed by the aggregation of platelets inside the vessels. The disorder in which a person generates a thrombus in a vessel is called thrombosis.
- Hypertension is a chronic medical condition in which a person suffers persistently from high blood pressure.
- Angina is a severe, radiating chest pain due to the lack of blood (and oxygen) supply to the heart muscle, generally due to obstruction or spasm of the coronary arteries.
- A surgery where the chest is opened and surgery is performed on the heart muscle, valves, arteries, or other heart structures is termed as open heart.
- The lymphatic system is a network of vessels found in vertebrates that carry a milky fluid called lymph. Lymph vessels, at certain points , have masses of connective tissues called lymph nodes.

EXERCISE

A. Choose the correct answers in the following questions.

1. The foramen ovale in the fetal heart is located in the:

   a. Right atrium b. Left atrium

   c. Interventricular septum d. Interatrial septum

2. Colouration of the skin of a baby turns bluish shortly after birth. The reason may be:

   a. Increased level of anesthesia was administered to her/his mother.

   b. Baby has an unclosed foramen ovale.

   c. Some hormonal disturbance has caused discolouration.

   d Blood capillaries in the liver are not working efficiently.

3. Lymph is poured back to the circulatory system in

   a. pulmonary vein b. hepatic portal vein

   c. subclavian vein d. renal vein

4. The interventricular septum and the intra-atrial septum separate the:

   a. chambers of the heart b. chambers of the lungs

   c. aorta and pulmonary artery d. bicuspid and tricuspid valves

5. The systemic circuit of the cardiovascular system extends:

   a. from the heart to the lungs.

   b. from heart to the coronary arteries.

   c. from the heart to the body's organs and tissues.

   d. from the gastrointestinal tract to the liver.

6. The only vein in the body that transports oxygen-rich blood is the:

   a. coronary vein b. hepatic portal vein

   c. pulmonary vein d. aortic vein

7. The semilunar valves prevent blood from flowing backwards:

   a. into the atria b. into the ventricles

   c. into the aorta d. into the vena cava

EXERCISE

8. All the following apply to the bicuspid valve EXCEPT:
   a. It is also called the mitral valve
   b. It is a semilunar valve
   c. It is found on the left side of the heart
   d. It prevents blood from backing into the left atrium
9. The condition called arrhythmia is characterized by:
   a. rapid heart contraction.
   b. irregular heart rhythms.
   c. mitral valve prolapse.
   d. semilunar valve dysfunction.

10. Intercalated disks are found:
    a. between the right side and right side of the heart.
    b. between the flaps of the tricuspid valve.
    c. where the aorta joins the pulmonary artery.
    d. between the cardiac muscle cells.

11. Blood flowing through a vein tends to:
    a. pulse. b. collect blood.
    c. carry oxygen to the body cells. d. flow at a faster rate than in the artery.

B. Write short answers to the following questions.

1. How the interstitial fluid is formed?
2. Why the normal value of BP increases in old age? Explain your answer.
3. If the baroreceptors are removed from an artery what would be the effect ?
4. What changes occur in BP and cardiac out put during a strenuous exercise?
5. If we don't take water the whole day in the month of June, what would be the effect on volume of lymph?

C. Write in detail the answers of following questions.

1. Draw the internal structure of a human heart and show the blood circulation with the help of arrows.
2. Name major arteries and veins and discuss the organs to which they target.
3. Define blood pressure and explain its periods of systolic and diastolic pressure.

EXERCISE

4. Describe the principles of angiography.
5. Describe the functions of lymph nodes and state the role of spleen as containing lymphoid tissue.
6. List the changes in life styles that can protect man from hypertension and cardiac problems.
7. Identify the factors causing atherosclerosis and arteriosclerosis.

Projects:

- Conduct a survey to identify major hospitals of cardiology working in your area. In case of no such facility available , identify the nearest cardiac centre and its utility or otherwise for cardiac patients in case of emergency situation.
- Record an interview with a patient who has undergone coronary bypass surgery. Collect information regarding his/her past life style, dietary habits and genetic history. Draw a conclusion from this data for preventing cardiac issues and for sustaining healthy life.

Chapter

13 Immunity

At the end of this chapter the students will be able to:

- Describe the structural features of human skin that make it impenetrable barrier against invasion by microbes.
- Explain how oil and sweat glands within the epidermis inhibit the growth and also kill microorganisms.
- Recognize the role of the acids and enzymes of the digestive tract in killing the bacteria present in food.
- State the role of the ciliated epithelium of nasal cavity and of the mucous of the bronchi and bronchioles in trapping air borne microorganisms.
- Describe the role of macrophages and neutrophils in killing bacteria.
- Explain how the Natural Killer (NK) cells kill the cells that are infected by microbes.
- State how the proteins of the complement system kill bacteria and how the interferons inhibit the ability of viruses to infect cells.
- State the events of the inflammatory response as one of the most generalized nonspecific defenses.
- Outline the release of pyrogens by microbes and their effect on hypothalamus to boost the body's temperature.
- List the ways the fever kills microbes.
- Categorize the immune system that provides specific defense and acts as the most powerful means of resisting infection.
- Identify monocytes, T-cells and B-cells as the components of the immune system.
- State the inborn and acquired immunity as the two basic types of immunity.
- Differentiate the two types of acquired immunity (active and passive immunity).
- Identify the process of vaccination as a means to develop active acquired immunity.
- Describe the roles T-cells in cell-mediated immunity.
- Describe the role of B-cells in antibody-mediated immunity.
- Draw the structural model of an antibody molecule.
- Explain the role of memory cells in long-term immunity.
- Define allergies and correlate the symptoms of allergies with the release of histamines.
- Describe the autoimmune diseases.

Introduction

The immune response is how your body recognizes and defends itself against bacteria, viruses, and substances that appear foreign and harmful. Immunology is one of the branch of Biology which is the study of our protection from foreign macromolecules or invading organisms and our responses to them. These invaders include viruses, bacteria, protozoa or even larger parasites. In addition, we develop immune responses against our own proteins (and other molecules) in autoimmunity and against our own aberrant cells in tumor immunity. Organisms must find a means of defense against antigens otherwise bacteria, fungi and viruses would replicate out of control and results in the destruction of the body. Therefore organisms employ many types of defense to stop this happening. Means of defense can be categorized into first second and third lines of defense. In this chapter you will see the overall setup which is running the immune system in our body and how our body triggers responses and employs methods which ensures our healthy survival.

13.1 First line of Defense

In humans, the skin is the largest organ of the integumentary system. Skin is regarded as one of the first line of defense because it provides an almost impenetrable biological barrier protecting the internal environment. It protects the body (especially the underlying tissues) against pathogens and excessive water loss. It is also involved in providing insulation, temperature regulation and sensation.

13.1.1 Physical Components of the Skin's Defense

Our body's first line of defense is nonspecific and includes structures, chemicals, and processes that work to prevent pathogens entering the body. These first line defenders include the skin and mucous membranes of the respiratory, digestive, urinary, and reproductive systems. Skin is comprised of two main layers.

- Epidermis
- Dermis

a. The Epidermis

The epidermis is composed of multiple layers of tightly packed cells, which few pathogens can penetrate on their own. In addition to this structural barrier, the natural shedding of dead skin cells removes many attached microorganisms. Then there are other cells called epidermal dendritic cells that actively patrol the skin to phagocytize (engulf and digest) pathogens.

b. The Dermis

The dermis is situated beneath the epidermis and contains protein fibers called collagen. Collagen is a tough fibrous protein which gives skin the strength and

pliability to resist abrasions that could introduce microorganisms.

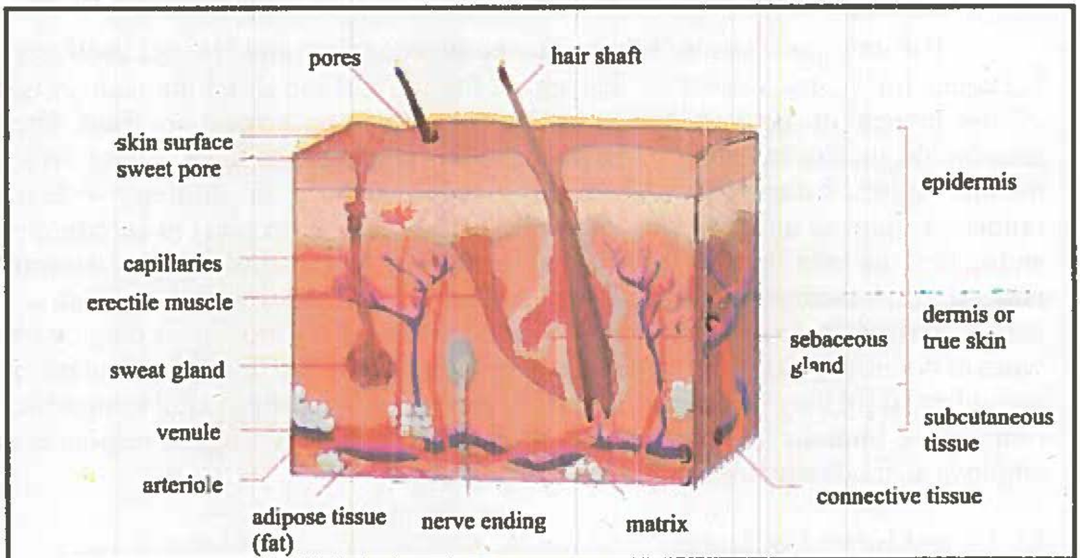


Fig: 13.1 Section of skin

13.1.2 Components of the Skin's Defense

a. Perspiration

Secreted by the skin's sweat glands, perspiration contains salt and enzymes. Few microbes can live in a highly saline environment, like that of the skin's surface. The lysozymes in sweat are a type of enzyme that can destroy the cell walls of bacteria.

b. Sebuin

Sebum is secreted by skins sebaceous (oil) glands. The oil helps keep skin pliable and less likely to break or tear and also lowers the pH of the skin to a more acidic level that inhibits the growth of many types of bacteria.

13.1.3 Defense against Infection in Digestive Tract

Proper levels of HCI in the stomach are our first line of defense against bacterial and viral infections. All day long we unavoidably ingest all kinds of bacteria and viruses through the mouth, nose and food we eat. These germs just cannot survive the trip into the stomach because of acidic environment. The healthy stomach essentially remains sterile.

Normally good bacteria, that live lower down in your digestive tract, can also move up into the stomach if it becomes more alkaline. Proper acid levels in the stomach prevent this over-growth from occurring.

13.1.4 Cilia and Mucus

The most important function of the nose and nasal cavity is to process each breath before it enters the lungs. This filtering process is important for several reasons. Considering the amount of air that passes through the respiratory system each day, it is important that the nose:

- Filter out dangerous particles (bacteria, viruses, dust, pollen etc.) that could otherwise enter into the lungs, causing damage. Tiny hairs (*cilia*) and a mucous membrane line the inside of the nose to trap particles before they enter the body. The cilia are capable of small movements and can direct the flow of *mucus* (a substance secereted by mucous membranes), removing it from the nasal cavity. Sneezing forces air through the nasal cavity and is also effective at removing particles and mucus.

- Warm each breath to prevent cold air from damaging sensitive lung tissue. The large amount of surface area and many blood vessels in the nasal cavity help warm each breath quickly as heat transfers from the blood to the passing air.

- Add moisture to each breath to prevent the airways and lungs from becoming dry and damaged. As air passes through the nasal cavity, moisture is transferred from the mucus secreted by the lining of the nasal cavity into the air.

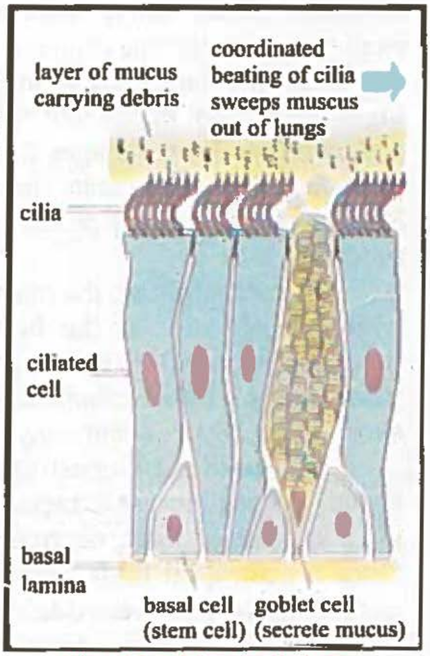


Fig: 13.2 Mucus lining

Because the nose and nasal cavity are so effective at filtering, warming and moisturizing each breath, it is generally better to breathe through the nose than the mouth. Though the mouth can allow a person to inhale more quickly, over time, mouth breathing can dry out the delicate tissue in the airways and lungs. Furthermore, oxygen may be easier for the lungs to extract from air that has been filtered, warmed and humidified through the nose and nasal cavities.

In normal lungs, the oxygen from the air is drawn through the nose and mouth, travels down the trachea into the right and left bronchus and bronchioles and then finally into millions of alveoli (air sacs). From the alveoli the oxygen is

absorbed into the blood stream and is carried to all parts of the body.

To help the breathing process, the lungs have their own natural clearance methods. Your airways produce a thin coat of mucous that catches the dust and bacteria that you breathe in daily. This thin mucous is swept up towards the windpipe by tiny beating hairs called cilia, where it can be coughed up or swallowed.

13.2 Second Line of Defense

Once pathogens are able to neutralize the responses from the first line of defense i.e skin and mucous membranee and are able to penetrate inside the body they are encounter by the second line of defense which is nonspecific because it handles a variety of microbes.

Fig: 13.3 Neutrophil

Nonspecific defense includes macrophages, neutrophils, natural killers cells, the complement system etc.

13.2.1 Role of Macrophages and Neutrophils

Monocytes and neutrophils are types of white blood cells. As we know that WBCs are involved in providing immunity to the body. Monocytes are released by the bone marrow, These float in the bloodstream from where they enter tissues and turn into macrophages. Of all blood cells, macrophages are the biggest. Most boundary tissue has its own macrophages. For example, alveolar macrophages live in the lungs and keep the lungs clean and disease free by ingesting foreign things like smoke, dust bacteria and microbes. Macrophages also swim freely. One of their jobs is to clean up dead neutrophils. Macropghages clean up pus as a part of the healing process.

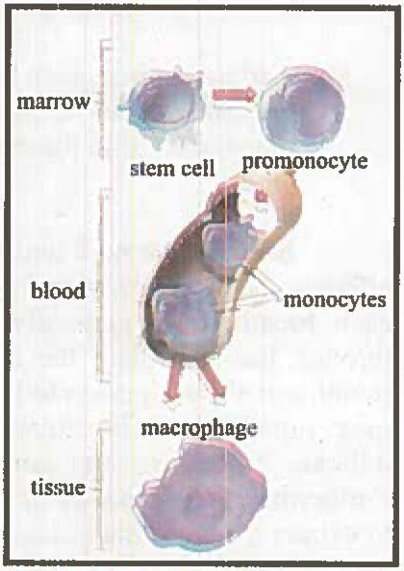


Fig: 13.4 Formation of macrophage.

Neutrophils are the most common form of white blood cells in the body. Bone marrow produces trillions of WBCs every day and releases them into the bloodstream, but their life span is short - generally less than a day.

Once in the bloodstream neutrophils can move through capillary walls into tissue. Neutorphils are attracted to foreign material, inflammation and bacteria. If you get a splinter or a cut, neutrophils will be attracted by a process called chemotaxis. Once a neutrophil finds a foreign particle or a bacteria it will engulf it, releasing enzymes, hydrogen peroxide and other chemicals from its granules to kill the bacteria. In a site of serious infection (where lots of bacteria have reproduced in the area), pus

will form. Pus is simply dead neutrophils and other cellular debris.

13.2.2 Role of Natural Killers (NK) Cells

Natural killer cells are a type of lymphocyte (a white blood cell) and a component of innate immune system. NK cells play a major role in the host-rejection of both tumours and virally infected cells. NK cells are cytotoxic; small granules in their cytoplasm contain special proteins such as perforin and proteases known as granzymes.

Upon release in close proximity to a cell selected for killing, perforin forms pores in the cell membrane of the target cell through which the granzymes and associated molecules can enter, inducing apoptosis.

The distinction between apoptosis and cell lysis is important in immunology - lysing a virus-infected cell would only release the virions, whereas apoptosis leads to destruction of the virus inside. NK cells are activated in response to interferons or macrophage-derived cytokines.

13.2.3 Complement System and interferons

If pathogenic bacteria get through all the immune system's initial defenses, the arsenal of the complement system is initiated.

The complement system includes proteins and white blood cells, which carry antibodies. The antibodies are microscopic killing cells that seek out anything they don't recognize as being part of the body.The proteins circulate in an inactive form, but in response to the recognition of molecular components of microorganism, they become sequentially activated, working in a cascade where in the binding of one protein promotes the binding of the next protein in the cascade. The white blood cells and the proteins work together to coat any invading bacteria with antigen, which often makes the bacteria incapable of reproducing or binds the bacterium to a toxic chemical to make it break apart. The white blood cells and the proteins work together to coat any invading bacteria with antigen, which often makes the bacteria incapable of reproducing or binds the bacterium to a toxic chemical to make it break apart.

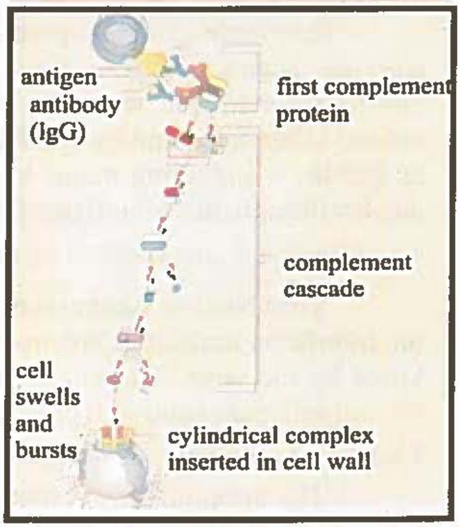


Fig: 13.5 Mechanism of complement system.

The cells in the blood that detect pathogenic bacteria and signal the complement system to get to work are macrophages. The bacteria are passed on to T cells and B cells that are able to recognize and remember how to manufacture the

specific antibody to break apart the bacteria.

13.2.4 Interferon

Body frequently encounter situations of viruses attacks. Although viruses are efficient source of some of the lethal infections but at the same time Allah has gifted us with set of proteins which provide an effective shield against viral attacks.

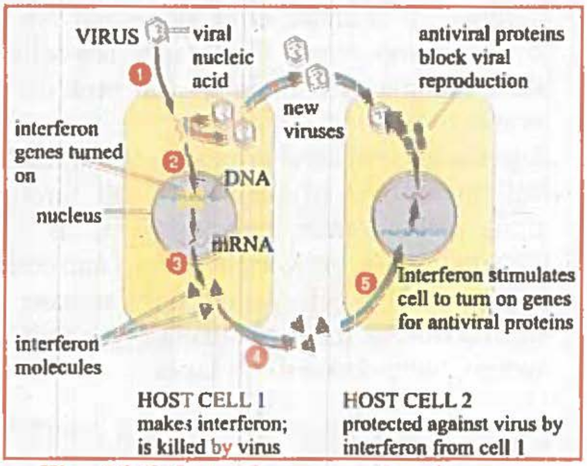


Fig: 13.6 Interferon mechanism against viruses.

The interferons are a group of natural proteins that are produced by human cells in response to viral infection and other stimuli. They have the ability to interfere with viruses that are replicating. There are three main types of interferon:Interferons beta and alpha—produced mainly by white blood cells and certain connective tissue cells called fibroblasts.

Interferon gamma—produced primarily by activated T cells. Interferons are antiviral agents and can fight tumors. These activities are co-ordinated by interferons-mediated activation of certain immune cells, such as macrophages and natural killer cells, and by enhancing cell surface expression of important immune molecules -- including major histocompatibility complex classes I and II, which display foreign (microbial) peptides for activation of T cells.

The Interferon mechanism against viruses

. Viral Nucleic Acid enters cell. Interferon genes of the cell's DNA are turned on. Interferon molecules are produced and released by the cell. The first host cell is killed by the virus. The interferons are recieved by another cell. In response, the second cell makes antiviral proteins, which block viral reproduction.

13.2.5 Inflammatory response as one of the non specific defenses

The inflammatory response (inflammation) occurs when tissues are injured by bacteria, trauma, toxins, heat, or any other cause. These damaged tissue releases chemicals including histamine, bradykinin, and serotonin. These chemicals cause blood vessels to leak fluid into the tissues, causing swelling. This helps isolate the foreign substance from further contact with body tissues. The chemicals also attract white blood cells called phagocytes that "eat" microorganisms and dead or damaged cells. This process is called phagocytosis. Phagocytes eventually die. Pus is formed from a collection of dead tissue, dead bacteria, and live and dead phagocytes.
The main symptoms of the inflammatory response are as follows.

- The tissues in the area are **red** and **warm**, as a result of the large amount of blood reaching the site.
- The tissues in the area are **swollen**, again due to the increased amount of blood and proteins that are present.
- The area is **painful**, due the expansion of tissues, causing mechanical pressure on nerve cells, and also due to the presence of pain mediators.

Once the inflammatory process has begun, it continues until the infection that caused it has been eradicated.

13.2.6 Pyrexia and Pyrogens

In case microbes proceeds in establishing a major infection the body often produces fever, which slows down microbial production and enhances the body's own fighting abilities.

Pyrexia (fever) means the elevation of body temperature above the normal range. It may be caused by abnormalities in the brain itself or by toxic substances that affect the temperature regulating centers. Such causes include bacterial or viral infections. Normally, the temperature of the body is regulated almost entirely by nervous feedback mechanisms, and almost all of these operate through a temperature regulating center located in the hypothalamus at the base of the brain. Nerve receptors in the skin and spinal cord provide feedback that drives the body to either conserve heat, produce increased quantities of heat (shivering), or increase heat loss (sweating or panting). Changes in the heat regulating process are constantly undergoing modifications that go unnoticed. In other words, heat regulation is not a static process but an ever-moving one that is important to normal body function.

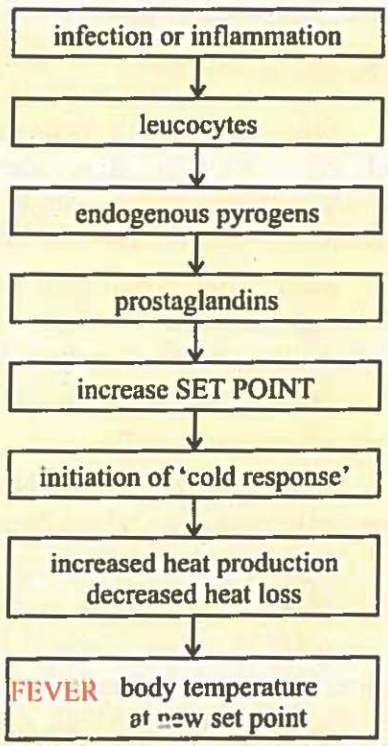


Fig: 13.7 Stages in the onset of pyrixia.

Substances that may cause the "set point" of the hypothalamic thermostat to rise are called pyrogens. Many proteins, breakdown products of proteins, and certain other substances, such as lipopolysaccharide toxins (LPS or endotoxin) secreted by bacteria, can act as pyrogens. It is pyrogens secreted by toxic bacteria or pyrogens released from degenerating tissues of the body

that cause fever during disease conditions. Pyrogens are extremely potent since as little as a few nanograms (nano = one billionth) injected into animals can cause a fever.

Pyrogens are produced by many microorganisms including bacteria, yeasts and moulds. Most potent pyrogens are the endotoxins produced from the cell walls of the Gram- negative bacteria.

Ways the fever kills microbes

When someone has a fever, the body raises the normal body temperature above 37.8°C (100°F) to try to kill bacteria or viruses in the body (this temperature is taken orally). Fever is actually the body's natural way of defending itself from invaders like viruses and bacteria, because many of them can't survive in the body due to the high temperature caused by a fever. High body temperatures also signal infection-fighting cells of the immune system such as phagocytes, neutrophils, and lymphocytes to defend and help fight off infections. The degree of temperature increase doesn't necessarily correspond to the severity of the illness. The fever response tends to be greater in children than adults. The two functions of fever are:

1. To stimulate the immune system.
2. To create an inhospitable environment for invading organisms. That is, to turn up the heat high enough that the invading microbes cannot live.

The Benefits of Fever

More antibodies -- cells trained to specifically attack the exact type of invader that your body is presently suffering from -- produced more specific to the agent of disease than any medicines.

More white blood cells produced, circulating, mobilizing and armed to fight off the invading bugs specific to the general category of invader.

More interferon produced which blocks spread of viruses to healthy cells.

Fig: 13.6 Fever has certain beneficial aspects too

Walling off of iron, which bacteria feed on.
Increased temperature, which directly kills microbes.

13.3 Third Line of Defense (The Specific Defense)

If a pathogen still manages to cross first and second line of defenses and get into your blood stream, you're not beaten yet! All cell membranes have protein coats that line the outside of them. Early on, when you were still developing as a baby, your body begins learning which cells belong to you and which don't. Now, your developed body has a good idea of whether cells are pathogens or not. This is accomplished by two defense mechanisims, cell mediated and humoral.

T lymphocytes or T cells, along with macrophages, oversee the Cell mediated response, while the B lymphocytes or B cells take charge of the humoral response.

Monocytes develop from stem cells in the bone marrow. They then go into blood, where they circulate for a while and then migrate into tissues. In the tissue they further mature into macrophages. Monocytes and macrophages play important roles in the immune defence and inflammation.

Lymphocytes are one of the five kinds of white blood cells or leukocytes), circulating in the blood. Although mature lymphocytes all look pretty much alike, they are extraordinarily diverse in their functions. The most abundant lymphocytes are:

- B-lymphocytes (B cells)
- T-lymphocytes (T cells).

B cells are produced in the bone marrow. The precursors of T cells are also produced in the bone marrow but leave the bone marrow and mature in the thymus. Each B cell and T cell is specific for a particular antigen.

For Your Information

All complement pathways carry out 6 beneficial innate defense functions. They:
1. Trigger inflammation.
2. Chemotactically attract phagocytes to the infection site.
3. Promote the attachment of antigens to phagocytes (enhanced attachment or opsonization).
4. Cause lysis of gram-negative bacteria and human cells displaying foreign epitopes.
5. Plays a role in the activation of naive B-lymphocytes.
6. Remove harmful immune complexes from the body.

13.4 Basic Types of Immunity

There are two main types of immunity :

1. Innate or Inborn or Natural immunity

The innate immunity system is what we are born with and it is nonspecific; all antigens are attacked pretty much equally. It is genetically based and we pass it on to our off springs. It is present from the birth and is inherited from the mother to offspring through the placenta.

2. Acquired or Adaptive immunity.

It is not present from the birth but is acquired during one's own life. It is developed by the organism in response to a disease caused by the infection of microbes or vaccine. In this, the protective lymphocytes of body produce antibodies which not only inactivate the antigens and relieve from an infectious disease but also provide immunity against further attack.

It is so as some antibody producing cells persist as "memory cells" for long period and produce antibodies immediately after second infection to counter it. The

acquired immunity so developed may be temporary (e.g., influenza) or permanent (e.g., measles, mumps, polio, smallpox) for life long.

13.4.1 Types of acquired immunity

(a) Active or Natural immunity

It is a long lasting immunity developed by antibodies produced by an individual's own cells. It is developed in three ways :

a. By having the disease e.g., chickenpox, mumps, measles etc.

b. By having a subclinical infection e.g. live 'Sabin' vaccine (against polio).

c. By having killed micro-organisms or detoxified toxins e.g., killed 'Salk' vaccine (against polio), tetanus toxoid (against tetanus).

(b) Passive or Artificial immunity

Passive immunity is "borrowed" from another source and it lasts for a short time. For example, antibodies in a mother's breast milk provide a baby with temporary immunity to diseases the mother has been exposed to. This can protect the baby against infection during the early years of childhood.

Everyone's immune system is different. Some people never seem to get infections, whereas others seem to be sick all the time. As people get older, they usually become immune to more germs as the immune system comes into contact with more and more of them. That's why adults and teens tend to get fewer colds than kids — their bodies have learned to recognize and immediately attack many of the viruses that cause colds.

13.4.2 Vaccination a mean to develop active acquired immunity

Immunization is the process where body is made immune or resistant to an infectious disease, typically by the administration of a vaccine. Vaccine stimulates the body's own immune system to protect the person against subsequent infection or disease. The word vaccination or vaccine had been evolved from vacca which means cow pus, which contains virus for cowpox. The cowpox and smallpox virus is very similar in structure. If the human body is exposed to the cowpox virus through vaccine, the body acquired immunization against smallpox. We can define vaccine as a immuno -biological substance which produce specific protection against a given disease. It stimulates the production of protective antibody and other immune mechanism.

Fig: 13.9 Polio vaccine is given against polio virus.

Vaccines may be prepared from live modified organisms, inactivated or killed organisms, extracted cellular fractions toxoids or combination of these. Prevention of disease is the need of the day.

The morbidity caused by the disease and rising costs of treating them requires us to focus more on their prevention. Immunization is among the most successful components of preventive medicine. It is effective public health intervention that has had the greatest impact on health of the people. Every year millions of children around the globe are saved from illness or death

because of vaccines.

13.5 Specific defense mechanisms

Specific defense mechanisms are effective against specific pathogens. There are two main types of specific defense mechanisms involved in the immune system.

a. Cell mediated immune response

b. The antibody mediated immune response

a. Cell mediated immune response

The cell-mediated immune system consists of T-cells which originate in the bone marrow, but moves to the thymus where their development is completed. T-cells are highly-specialized cells in the blood and lymph. They fight bacteria, viruses, fungi, protozoans, cancer, etc. within host cells and react against foreign matter such as organ transplants.

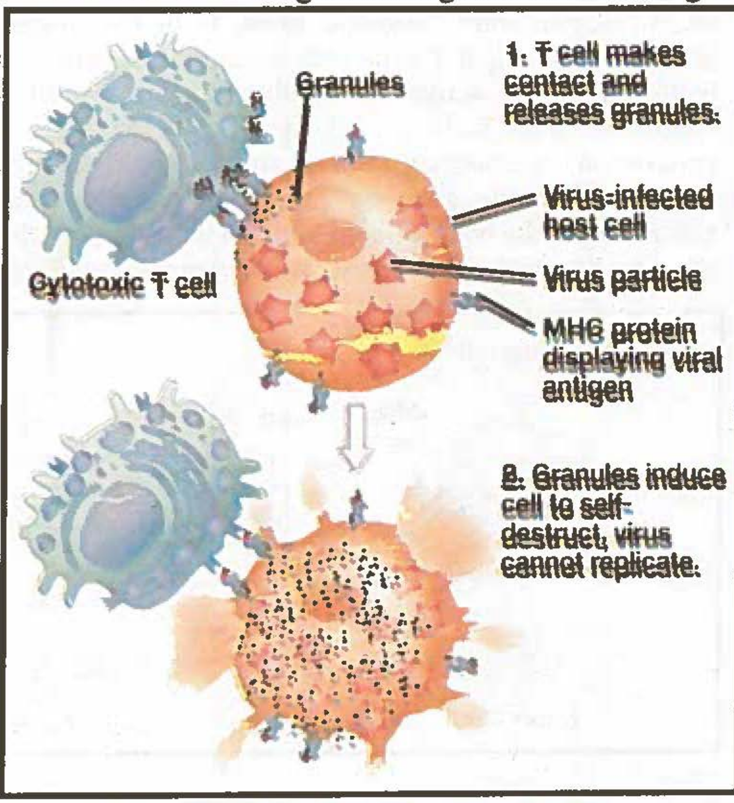


Fig: 13.10 Mechanism of specific defense.

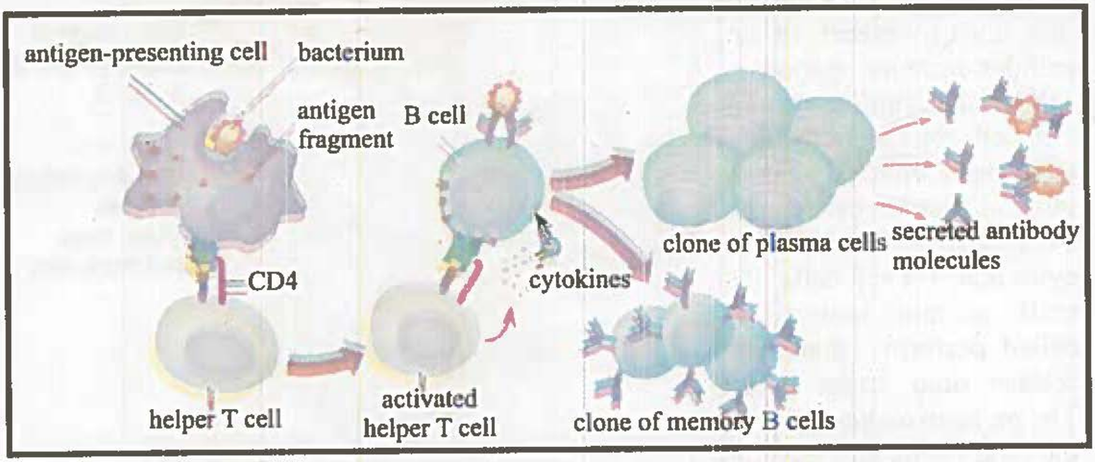
There are three kinds of T-cells. Cytotoxic T-cells directly kill invaders. Helper T-cells aid B cells and other T-cells to do their jobs. Suppressor T-cells suppress the activities of B- and other T-cells so they don't overreact. In the cellular immune response, cells of the immune system kill cells of the body that have been infected with a virus or that are cancerous. This response relies on cytotoxic T (Tc) cells, Tc cells contain molecules, called perforins, that they release onto target cells. The perforin makes holes in the target cells and thereby kills them. The cellular immune response occurs in two phases. In the first, called the activation phase, Tc cells that have the appropriate T-cell receptors are activated and triggered to divide repeatedly. In the second called the effectors phase, these activated Tc cells encounter target cells and kill them.

\b. The antibody mediated immune response

The humoral immune system consists of B-cells which originate in the Bone marrow and stay there to develop. B-cells can produce antibodies, but need exposure to foreign antigens to do so. These antigens are cell surface oligosaccharides and proteins which the cell uses as "ID tags".

Antibodies are chemically proteins present in blood plasma and lymph. They help in fighting bacteria and viruses in body fluids. All daughter cells of a B-cell will be able to produce the same antibodies as the mother cell. Antibodies bind to certain parts of an antigen to mark it for destruction (by the T-cells).

The body humoral or antibody mediated immune response begins in the same manner as the cell mediated response. But here the macrophages are joined by B cells. The pathogens activate only those B cells with matching receptors. These cells stand ready to enter the battle. Mean while the antigens presenting macrophages activate those helper T cells with matching receptors. These T cells in turn lead the battle front with activated B cells. Triggers by this meeting the helper release chemicals which make the selected B cells to go into rapid reproduction. Some B cells become memory cells ready to respond to a later invasion by the same pathogens but most become antibody producing factories called Plasma cells. Freely circulating in the body antibody dock with pathogens this neutralizes them or marks them for destruction by other weapons in our immune arsenal.



Fig; 13.11 The antibody mediated immune response.

13.5.1 Structural Model of Antibodies

Antibodies are immune system-related proteins called immunoglobulins. Each antibody consists of four polypeptides– two heavy chains and two light chains joined to form a "Y" shaped molecule. The amino acid sequence in the tips of the "Y"

varies greatly among different antibodies.

This variable region, composed of 110-130 amino acids, give the antibody its specificity for binding antigen.
The variable region includes the ends of the light and heavy chains. The constant region determines the mechanism used to destroy antigen. Antibodies are divided into five major classes, IgM, IgG, IgA, IgD, and IgE, based on their constant region structure
and immune function.

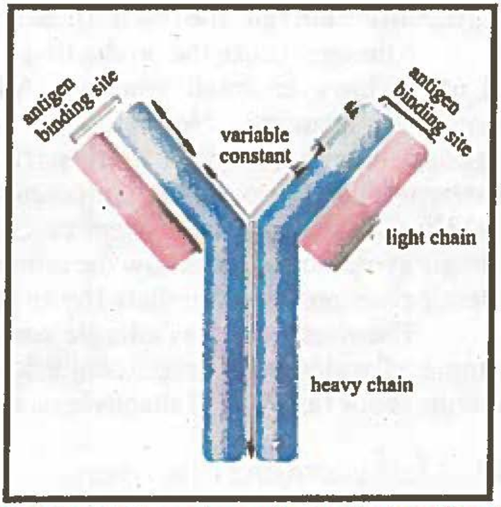


Fig: 13.12 Structure of a typical antibody.

13.6 Role of Memory Cells in Immunity

Neither the killer T-cells nor the B-cells just die off after they kill the pathogen. When their job is done, they leave behind memory cells. These memory cells are cells that stay behind and watch for the pathogen. If they find one, they start multiplying to kill it. Memory killer T-cells make killer T-cells and memory B-cells make B-cells. This process is so immediate and so explosive that the pathogen is killed off before it has a chance to infect you. Because of that, you are immune to that pathogen.

13.7 Allergies

Allergies are abnormal reactions to ordinarily harmless substances. The sensitizing substances, called allergens, may be inhaled, swallowed, or come into contact with the skin. Allergens that most frequently cause problems are: pollens, mold spores, house dust mites, animal danders, foods, insect bites or stings, plants, insect spores, latex, viruses, bacteria, medications and environmental conditions (such as cold temperatures).

Although allergies can develop at any age, the risk of developing allergies is genetic. It is related to ones family history of allergy. If neither parent is allergic, the

TIDBIT

One of the common allergies facing the city dwellers in Pakistan is pollen allergy. People with weak immune system fall easy victim to pollen allergy. Pollen allergy symptoms include sneezing and runny nose, itching and watering of eyes, coughing, difficulty in breathing, wheezing and eventually attacks of asthma. Main plants causing, this allergy, are mulberry in March-April while cannabis in June-July.

chance for allergies is about 15%. If one parent is allergic, the risk increases to 30% and if both are allergic, the risk is greater than 60%.

Allergens cause the production of immunoglobulin E (IgE), an antibody that all of us have in small amounts. Allergic persons, however, produce IgE in abnormally quantities. Normally, this antibody is important in protecting us from parasites, but not from other allergens. During the sensitization period in allergy, IgE is overproduced. It coats certain potentially explosive cells that contain chemicals including histamine. These chemicals, in turn, cause inflammation and the typical allergic symptoms. This is how the immune system becomes misguided and cause an allergic reaction when stimulated by an allergen.

The most common allergic conditions include hay fever (allergic rhinitis), asthma, allergic eyes (allergic conjunctivitis), allergic eczema, hives (urticaria), and allergic shock (also called anaphylaxis and anaphylactic shock).

13. 8 Autoimmune disorders

Autoimmune disorders are diseases that occur when the body produces an inappropriate immune response against its own tissues. Sometimes the immune system will cease to recognize one or more of the body's normal constituents as "self" and will produce autoantibodies – antibodies that attack its own cells, tissues, and/or organs. This causes inflammation and damage and leads to autoimmune disorders.

In a few types of autoimmune disease (such as rheumatic fever), a virus or infection with bacteria triggers an immune response and the antibodies or T-cells attack normal cells because some part of their structure resembles a part of the infecting microorganism. Symptoms of autoimmune disorders vary by the particular disorder but many include fatigue, dizziness, and low grade fever. Symptoms can also vary in severity over time.

Some of the autoimmune diseases include:

- **Lupus**, a chronic disease marked by muscle and joint pain and inflammation (the abnormal immune response also may involve attacks on the kidneys and other organs).
- **Juvenile rheumatoid arthritis**, a disease in which the body's immune system acts as though certain body parts (such as the joints of the knee, hand, and foot) are foreign tissue and attacks them.
- **Scleroderma**, a chronic autoimmune disease that can lead to inflammation and damage of the skin, joints, and internal organs.
- **Ankylosing spondylitis**, a disease that involves inflammation of the spine and joints, causing stiffness and pain.
- **Juvenile dermatomyositis**, a disorder marked by inflammation and damage of the skin and muscles.

13.9 Role of T-cells and B-cells in Transplant Rejection

Transplantation is the act of transferring cells, tissues, or organs from one site to another. The malfunction of an organ system can be corrected with transplantation of an organ (e.g kidney, liver, heart, lung, or pancreas) from a donor. However, the immune system remains the most formidable barrier to transplantation as a routine medical treatment. The immune system has developed elaborate and effective mechanisms to combat foreign agents. These mechanisms are also involved in the rejection of transplanted organs, which are recognized as foreign by the recipient's immune system.

Major Histocompatibility Complex (MHC) proteins are involved in the presentation of foreign antigens to T-cells, and receptors on the surface of the T-cell (TCR) are uniquely suited to recognition of proteins of this type. MHC are highly variable between individuals, and therefore the T-cells from the host recognize the foreign MHC with a very high frequency leading to powerful immune responses that cause rejection of transplanted tissue. Identical twins and cloned tissue are MHC matched, and are therefore not subject to T-cell mediated rejection.

KEY POINTS

- The first line of defense is non-specific and is part of the innate immune system. The first line of defense consists of: 1) physical barriers 2) chemical barriers.
- The second line of defense is also part of the non-specific, innate immune system and includes non-specific immune cells, chemical mediators, fever; inflammation, phagocytosis.
- The third line of defense is part of the adaptive or acquired immune system. This line of defense provides specific, long-term protection against microbes. The third line of defense includes: 1) T-cells; 2) B-cells and 3) antibodies.
- Neutrophils are granular, non-specific immune cells that patrol the borders of the body and eliminate microbes by phagocytosis.
- Monocytes are agranular, non-specific immune cells that circulate in the blood and mature into macrophages when they migrate into tissues.
- Macrophages are agranular, non-specific immune cells that perform the following functions: 1) phagocytosis (professional eaters); 2) sound chemical alarm to alert other immune cells; and 3) present information about the foreign microbes (antigens) to the T cells, which are the generals of the immune army.
- Phagocytosis is a second line of defense process in which foreign materials (microbes) are engulfed and broken down by neutrophils or macrophages within a digestive compartment known as the lysosome.
- Inflammation is a non-specific response to tissue injury or infection that: 1) walls off damaged or infected tissue; 2) recruits immune cells to the site of injury or infection; and 3) clears away microbes or damaged cells so tissue repair can occur.
- Fever is an increase in body temperature induced by pyrogens and regulated by the hypothalamus, which decreases bacterial cell growth and increases immune cell activity.
- Interferons are anti-viral proteins released by virally-infected cells that help prevent the spread of infection to neighboring cells by degrading viral

KEY POINTS

DNA/RNA and blocking production of viral proteins.

- Complement is a set of immune proteins that aid or "complement" immune function.. Complement proteins form the membrane attack complex, which forms holes on the surface of targeted microbes and leads to their lysis.
- Vaccine as a immuno -biological substance which produce specific protection against a given disease. It stimulates the production of protective antibody and other immune mechanism.
- There are two main types of specific defense mechanisms involved in the immune system.: Cell mediated immune response and the antibody mediated immune response.
- Antibodies are immune system-related proteins called immunoglobulins.
- Allergens cause the production of immunoglobulin E (IgE), an antibody that all of us have in small amounts. Allergic persons, however, produce IgE in abnormally large quantities
- When the body produces an inappropriate immune response against its own tissues it results in the autoimmune disorders.

EXERCISE

A. Select the best answers for the following questions.

1. Which of these is not true of both T cells and B cells?
   a. They are both lymphocytes.
   b. They both are responsible for immunity
   c. They both pass through the thymus.
   d. They both have receptor sites..

2. Memory cells of the immune system are derived from:
   a. T lymphocytes
   b. B lymphocytes
   c. plasma cells
   d. Both a and b.

3. Which one of these is specifically responsible for antibody mediated immunity?
   a. T cells
   b. Epithelial cells
   c. Platelets
   d. Plasma cells

4. T cells:
   a. are responsible for cell mediated immunity.
   b. cause tumors in the body.
   c. stimulate and suppress red blood cells.
   d. helps in regeneration process.

5. Compound formed in an organism for inhibiting growth of another organism is:
   a. Antigen
   b. Antibody
   c. Antibiotic
   d. Antiallergic

6. Antigen binding site in an antibody is found between:
   a. two light chains.
   b. two heavy chains.
   c. one heavy and one light chain.
   d. two heavy and two light chain.

7. Humoral immunity is due to:
   a. T-lymphocytes
   b. L- lymphocytes
   c. P- lymphocytes
   d. B- lymphocytes

EXERCISE

8. Hypersensitivity to an allergen is due to:
   a. Increase in temperature
   b. Food habits
   c. Age
   d. Aberrent functioning of immune system

9. Surgical removal of thymus of a new born shall result in failure to produce:
   a. Monocytes
   b. B-Lymphocytes
   c. T- lymphocytes
   d. Basophills

B. Write short answers to the following questions.

1. What are pyrogens? How they affect the hypothalamus?
2. List three benefits of fever.
3. How interferons inhibit the ability of viruses to infect cells?
4. What would happen if mucous of bronchi fails to do it job?
5. What are the agent of nonspecific defense and specific defense?
6. Define allergy and allergens. List down some common allergic conditions.
7. Differentiate between the two types of acquired immunity.

C. Write answers of the following questions in detail.

1. What are the main events of inflammatory response?
2. Describe the structural features of human skin which provide effective control against microbes.
3. How macrophages and neutrophils help in killing bacteria?
4. How cell mediated immunity is attained?
5. What do you mean by autoimmune diseases? Give some examples of autoimmune diseases.
6. Describe the role of T-cells and B-cells in transplant rejections.

Projects:

- Vaccination is a means to develop active acquired immunity. It is one of the precautionary measure recommended against different diseases. Write an informative article on vaccination programme being implemented by the Govt for new born infants. Identify the chemical nature of the vaccines being used in this programme.
- Make a model of a structure of a typical antibody.

GLOSSARY

A

abscisic acid (ABA)
A plant hormone that generally acts to inhibit growth, promote dormancy, and help the plant tolerate stressful conditions.

abscission
In plants, the dropping of leaves, flowers, fruits, or stems at the end of a growing season, as the result of formation of a two-layered zone of specialized cells (the abscission zone) and the action of a hormone (ethylene).

absorption
The movement of water and dissolved substances into a cell, tissue, or organism.

absorption spectrum
The range of a pigment's ability to absorb various wavelengths of light.

acetyl CoA
The entry compound for the Krebs cycle in cellular respiration; formed from a fragment of pyruvate attached to a coenzyme.

acoelomate
A solid-bodied animal lacking a cavity between the gut and outer body wall.

activation energy
The energy that must be possessed by atoms or molecules in order to react.

active site
The specific portion of an enzyme that attaches to the substrate by means of weak chemical bonds.

active transport
The movement of a substance across a biological membrane against its concentration or electrochemical gradient, with the help of energy input and specific transport proteins.

adenosine diphosphate (ADP)
A nucleotide consisting of adenine, ribose, and two phosphate groups; formed by the removal of one phosphate from an ATP molecule.

adenosine monophosphate (AMP)
A nucleotide consisting of adenine, ribose, and one phosphate group; can be formed by the removal of two phosphates from an ATP molecule; in its cyclic form, functions as a "second messenger" for a number of vertebrate hormones and neurotransmitters.

adenosine triphosphate (ATP)
An adenine-containing nucleoside triphosphate that releases free energy when its phosphate bonds are hydrolyzed. This energy is used to drive endergonic reactions in cells.

allergic reaction
An inflammatory response triggered by a weak antigen (an allergen) to which most individuals do not react; involves the release of large amounts of histamine from mast cells.

alternation of generations
A life cycle in which there is both a multicellular diploid form, the sporophyte, and a multicellular haploid form, the gametophyte; characteristic of plants.

amino group
A functional group that consists of a nitrogen atom bonded to two hydrogen atoms; can act as a base in solution, accepting a hydrogen ion and acquiring a charge of +1.

anaerobic
Lacking oxygen; referring to an organism, environment, or cellular process that lacks oxygen and may be poisoned by it.

antheridium *pl.* **antheridia**

In plants, the male gametangium, a moist chamber in which gametes develop.

anthocyanin

Natural water-soluble pigments of blue, purple or red which are dissolved in the cell-sap vacuole of plant cells.

antibiotic

A chemical that kills bacteria or inhibits their growth.

antibody

An antigen-binding immunoglobulin, produced by B cells, that functions as the effector in an immune response.

antigen

A foreign macromolecule that does not belong to the host organism and that elicits an immune response.

aorta

The major artery in blood-circulating systems; the aorta sends blood to the other body tissues.

apical dominance

Concentration of growth at the tip of a plant shoot, where a terminal bud partially inhibits axillary bud growth.

apical meristem

Embryonic plant tissue in the tips of roots and in the buds of shoots that supplies cells for the plant to grow in length.

apoplast

In plants, the nonliving continuum formed by the extracellular pathway provided by the continuous matrix of cell walls.

apoptosis

Programmed cell death brought about by signals that trigger the activation of a cascade of "suicide" proteins in the cells destined to die.

assimilation

The energy-requiring process by which plant cells convert nitrate ions (NO_3^-) taken up by the roots of plants into ammonium ions (NH_4^+), which can then be used in the synthesis of amino acids and other nitrogenous compounds.

atrioventricular valve

A valve in the heart between each atrium and ventricle that prevents a backflow of blood when the ventricles contract.

autoimmune disease

An immunological disorder in which the immune system turns against itself.

B

B cell

A type of lymphocyte that develops in the bone marrow and later produces antibodies, which mediate humoral immunity.

bark

All tissues external to the vascular cambium in a plant growing in thickness, consisting of phloem, phelloderm, cork cambium, and cork.

bile

A yellow secretion of the vertebrate liver, temporarily stored in the gallbladder and composed of organic salts that emulsify fats in the small intestine.

biochemical pathway

An ordered series of chemical reactions in a living cell, in which each step is catalyzed by a specific enzyme; different biochemical pathways serve different functions in the life of the cell.

bioenergetics

The study of how organisms manage their energy resources.

biosynthesis

Formation by living organisms of organic compounds from elements or simple compounds.

blood pressure

The hydrostatic force that blood exerts against the wall of a vessel.

bond energy

The quantity of energy that must be absorbed to break a particular kind of chemical bond; equal to the quantity of energy the bond releases when it forms.

bud

(1) In plants, an embryonic shoot, including rudimentary leaves, often protected by special bud scales. (2) In animals, an asexually produced outgrowth that develops into a new individual.

bulb

A modified bud with thickened leaves adapted for underground food storage.

C_4 pathway

The set of reactions by which some plants initially fix carbon in the four-carbon compound oxaloacetic acid; the carbon dioxide is later released in the interior of the leaf and enters the Calvin cycle.

C_4 plant

A plant that prefaces the Calvin cycle with reactions that incorporate CO_2 into four-carbon compounds, the end-product of which supplies CO_2 for the Calvin cycle.

callus

In plants, undifferentiated tissue; a term used in tissue culture, grafting, and wound healing.

Calvin cycle

The second of two major stages in photosynthesis (following the light reactions), involving atmospheric CO_2 fixation and reduction of the fixed carbon into carbohydrate.

carcinogen

A chemical agent that causes cancer.

cardiac muscle

A type of muscle that forms the contractile wall of the heart; its cells are joined by intercalated discs that relay each heartbeat.

catalyst

A substance that lowers the activation energy of a chemical reaction by forming a temporary association with the reacting molecules; as a result, the rate of the reaction is accelerated. Enzymes are catalysts.

cell cycle

An ordered sequence of events in the life of a dividing eukaryotic cell, composed of the M, G_1, S, and G_2 phases.

cell-mediated immunity

The type of immunity that functions in defense against fungi, protists, bacteria, and viruses inside host cells and against tissue transplants, with highly specialized cells that circulate in the blood and lymphoid tissue.

cell plate

A double membrane across the midline of a dividing plant cell, between which the new cell wall forms during cytokinesis.

centromere

The centralized region joining two sister chromatids.

centrosome

Material present in the cytoplasm of all eukaryotic cells and important during cell division; also called microtubule-organizing center.

chitin

A structural polysaccharide of an amino sugar found in many fungi and in the exoskeletons of all

arthropods.

cholesterol

A steroid that forms an essential component of animal cell membranes and acts as a precursor molecule for the synthesis of other biologically important steroids.

coenzyme

An organic molecule serving as a cofactor. Most vitamins function as coenzymes in important metabolic reactions.

cofactor

Any nonprotein molecule or ion that is required for the proper functioning of an enzyme. Cofactors can be permanently bound to the active site or may bind loosely with the substrate during catalysis.

cohesion

The binding together of like molecules, often by hydrogen bonds.

cohesion species concept

The idea that specific evolutionary adaptations and discrete complexes of genes define species.

cork

A secondary tissue that is a major constituent of bark in woody and some herbaceous plants; made up of flattened cells, dead at maturity; restricts gas and water exchange and protects the vascular tissues from injury.

cork cambium

A cylinder of meristematic tissue in plants that produces cork cells to replace the epidermis during secondary growth.

cytokines

In the vertebrate immune system, protein factors secreted by macrophages and helper T cells as regulators of neighboring cells.

cytosol

The semifluid portion of the cytoplasm.

D

day-neutral plant

A plant whose flowering is not affected by photoperiod.

dehydration reaction

A chemical reaction in which two molecules covalently bond to one another with the removal of a water molecule.

diastole

The stage of the heart cycle in which the heart muscle is relaxed, allowing the chambers to fill with blood.

diastolic pressure

The pressure in an artery during the ventricular relaxation phase of the heart cycle.

dioecious

Referring to a plant species that has staminate and carpellate flowers on separate plants.

dispersion

The distribution of individuals within geographical population boundaries.

double fertilization

A mechanism of fertilization in angiosperms, in which two sperm cells unite with two cells in the embryo sac to form the zygote and endosperm.

double helix

The form of native DNA, referring to its two adjacent polynucleotide strands wound into a spiral shape.

E

electromagnetic spectrum: The entire spectrum of radiation; ranges in wavelength from less than a nanometer to more than a kilometer.

electron acceptor: Substance that accepts or receives electrons in an oxidation-reduction reaction, becoming reduced in the process.

electron carrier: A molecule that conveys electrons; one of several membrane proteins in electron transport chains in cells. Electron carriers shuttle electrons during the redox reactions that release energy used to make ATP.

electron transport chain: A sequence of electron-carrier molecules (membrane proteins) that shuttle electrons during the redox reactions that release energy used to make ATP.

endergonic reaction: A nonspontaneous chemical reaction in which free energy is absorbed from the surroundings.

energy of activation (E_A): The amount of energy that reactants must absorb before a chemical reaction will start.

exergonic reaction: A spontaneous chemical reaction in which there is a net release of free energy.

exocrine glands

Glands, such as sweat glands and digestive glands, that secrete their products into ducts that empty onto surfaces, such as the skin, or into cavities, such as the interior of the stomach.

exocytosis

The cellular secretion of macromolecules by the fusion of vesicles with the lasma membrane

F

facilitated diffusion: The spontaneous passage of molecules and ions, bound to specific carrier proteins, across a biological membrane down their concentration gradients.

fatty acid: A long carbon chain carboxylic acid. Fatty acids vary in length and in the number and location of double bonds; three fatty acids linked to a glycerol molecule form fat.

fibrin: The activated form of the blood-clotting protein fibrinogen, which aggregates into threads that form the fabric of the clot.

filtration: The first stage of kidney function; blood plasma is forced, under pressure, out of the glomerular capillaries into Bowman's capsule, through which it enters the renal tubule.

flaccid: Limp; walled cells are flaccid in isotonic surroundings, where there is no tendency for water to enter.

fossil: The remains of an organism, or direct evidence of its presence (such as tracks). May be an unaltered hard part (tooth or bone), a mold in a rock, petrification (wood or bone), unaltered or partially altered soft parts (a frozen mammoth).

G

gastric: Pertaining to the stomach.

gastrin: A digestive hormone, secreted by the stomach, that stimulates the secretion of gastric juice.

gastrovascular cavity

The central digestive compartment, usually with a single opening that functions as both mouth and anus.

glucagon

A peptide hormone secreted by pancreatic endocrine cells that raises blood glucose levels; an antagonistic hormone to insulin.

glycerol: A three-carbon molecule with three hydroxyl groups attached; a glycerol molecule

guard cell: A specialized epidermal plant cell that forms the boundaries of the stomata.

gH

helper T cell (T_H): A type of T cell that is required by some B cells to help them make antibodies or that helps other T cells respond to antigens or secrete lymphokines or interleukins.

histamine (hiss-tuh-meen): A substance released by injured cells that causes blood vessels to dilate during an inflammatory response.

histone (hiss-tone): A small protein with a high proportion of positively charged amino acids that binds to the negatively charged DNA and plays a key role in its chromatin structure.

humoral immunity (hyoo-mur-al): The type of immunity that fights bacteria and viruses in body fluids with antibodies

Inflammation: A body strategy initiated by the release of chemicals following injury or infection which brings additional blood with its protective cells to the injured area.

Long-day plants: Plants that flower when the length of daylight exceeds some critical period.

Meristems: In plants, clusters of cells that retain their ability to divide, thereby producing new cells. One of the four basic tissues in plants.

Microfilaments: Thin protein fibers that are responsible for maintenance of cell shape, muscle contraction and cyclosis.

Microtubules: Thin, hollow tubes in cells; built from repeating protein units of tubulin. Microtubules are components of cilia, flagella, and the cytoskeleton.

parathyroid hormone (PTH). When blood calcium levels are low, PTH is secreted, causing calcium to be released from bone.

Pelagic zone: The open oceans, divided into threelayers:1) photo- or epipelagic,(sunlit), 2) mesopelagic (dim light), 3) aphotic or bathypelagic (always dark).

Placenta: In mammals (exclusive of marsupials and monotremes), the structure through which nutrients and wastes are exchanged between the mother and embryo fetus. Develops from both embryonic and uterine tissues.

Plasmid: A small circle of ON A in bacteria in addition to its own chromosome.

component of seed coats and nuts.

Sclerenchyma: Component of the ground tissue system of plants. They are thick walled cells of various shapes and sizes, providing support or protection. They continue to function after the cell dies.

Short -day plants: Plants that flower in late summer or fall when the length of daylight becomes shorter than some critical period.

Thigmotropism: Changes in plant growth stimulated by contact with another object, e.g., vines climbing on cement walls.

Transformation: A genetic transfer mechanism that produces new DNA in bacteria when DNA from a new organism is combined with the DNA of the host cell.

Translation: The cell process that converts a sequence of nucleotides in mRNA into a sequence of amino acids.

Vernalization: The promotion of flowering or germination after a plant is exposed to low temperatures.

Viviparous: Referring to an animal whose offspring are born rather than hatched through an egg.

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